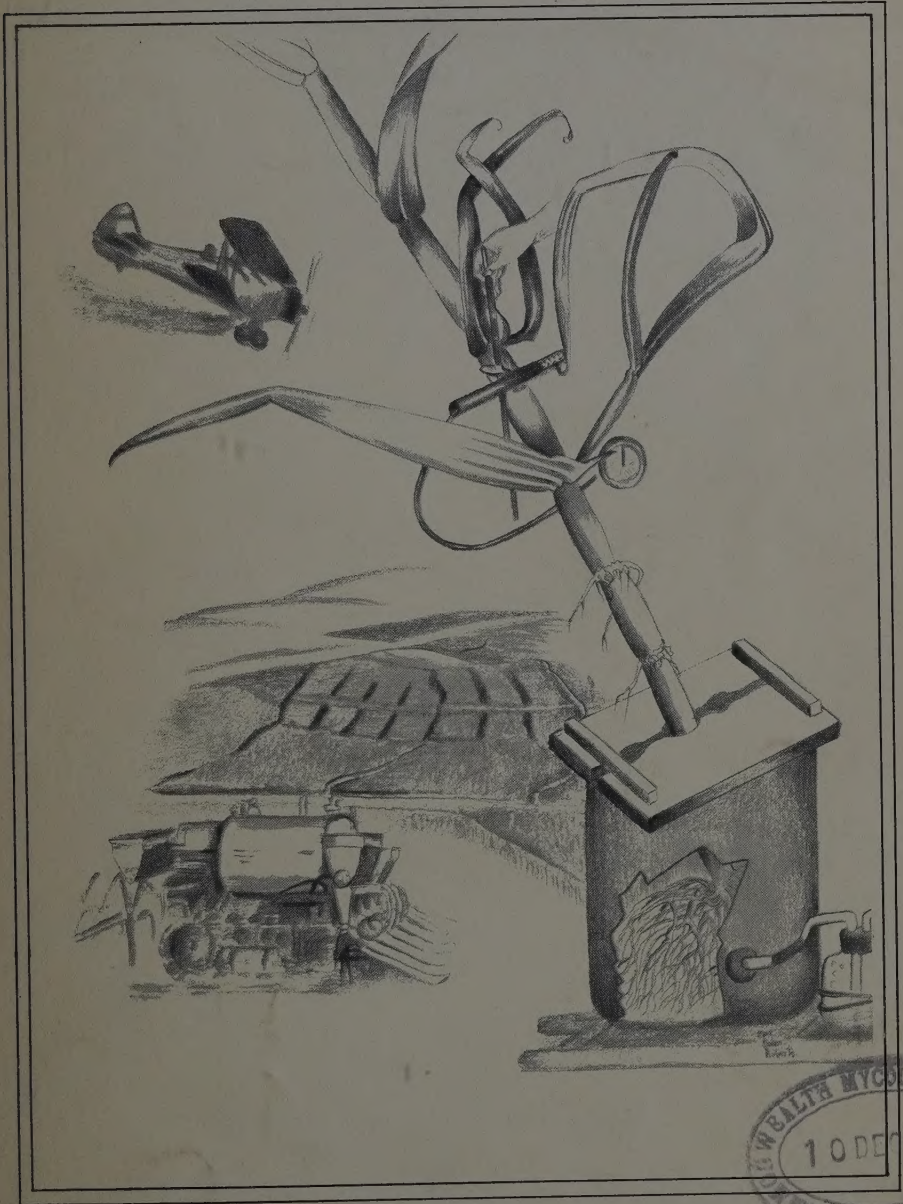


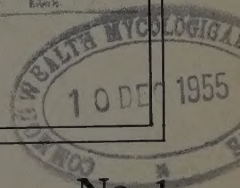
# HAWAIIAN PLANTERS' RECORD



Vol. LV

1955

No. 1





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A publication devoted to the sugar interests of Hawaii and issued by the Experiment Station for circulation among plantations of the Hawaiian Sugar Planters' Association.

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# CANE NUTRITION AND FERTILIZATION SEMINAR

Experiment Station, HSPA — Agee Hall

September 30 and October 1, 1954

## INTRODUCTION

L. D. BAVER

Welcome to this important seminar on cane nutrition and fertilization! The next two days should contribute much to a better understanding of the cane plant and how it should be fertilized. The nutrition of any crop grown in soil is not simple to study nor to understand. One must cope with many factors other than nutrients in solving problems of the most efficient production. Among these factors are the variations that exist in soil properties, the differences as well as fluctuations in climate, the rugged individualism of varietal behavior, the insidious action of symptomless diseases, and a wide range of cultural practices which reflect the personal whims of man. The production of sugar cane in Hawaii is no exception to the general experience. We have a wide variety of soil conditions with respect to both physical properties and fertility. We have variations in rainfall, temperature, sunlight energy, and wind velocities. We recognize the good and bad characteristics of varieties as they respond to ecological conditions. We, too, have differences of opinions on the culture of cane.

The complexities of the problem as well as its importance to the Hawaiian sugar industry challenge each of us to apply the tools of science toward the attainment of an understanding of the nutrition of the cane plant that can be interpreted with ease and confidence in terms of field fertilization. New tools as well as new ideas have made possible, during the past five or six years, the obtaining of factual data that promise to help us reach our goal. Radioactive isotopes are giving us relatively rapid and technically sound results. We can trace what happens within the cane plant. Controlled environments have pointed to interactions of climate and nutrient absorption that are proving most helpful in understanding cane nutrition. These are but two examples of the types of scientific tools that are being used in sugar cane research.

Sufficient progress has been made to warrant our getting together in this seminar to discuss objectively the information at hand. We realize that the final answers have not been obtained, that a more thorough analysis of existing data must be made, that more basic research is needed. However, it is important that we weigh the merits and weaknesses of our present knowledge, that we attempt to integrate our existing know-how in terms of practical application, and that we point out the gaps in our understanding of the cane plant that need to be filled by additional research. I hope we will achieve these expectations during the next two days. Each of you can contribute much to the seminar by participating in the discussion period following each paper. May the results of this seminar bear fruit in terms of better cane fertilization!



# ABSORPTION AND DISTRIBUTION OF NUTRIENTS IN SUGAR CANE

## PART I: NITROGEN

GEORGE O. BURR AND DAVID TAKAHASHI\*

### INTRODUCTION

One of the long-term projects of the Physiology & Biochemistry Department has been the study of the uptake and distribution of nutrient elements in sugar cane.

The immediate objectives of these studies have been to find: (1) the response of different parts of the plant to nutrient levels; (2) the effect of temperature upon rate of uptake and final distribution of nutrients; and (3) the effects of age on composition. Ultimately the knowledge gained may be applied in fertilizer control when relationships between plant composition and yield have been established.

Nitrogen has been divided into several well-known fractions. It has been found that the 80 per cent alcohol-soluble fraction represents the mobile nitrogen which includes ammonia, asparagine and glutamine. Since this extract also contains the sugars and other interesting compounds, it has been used in many of the studies without further fractionation.

Use has been made of both ammonia and urea tagged with N15 to get a better insight into nitrogen movements.\*\* This new tool permits exchange studies and measurements of rates of movement which cannot be obtained in any other way.

### LEAF FEEDING

Recently there has been much interest in feeding plants dissolved nutrients through the leaves. In general, plants absorb some of almost any soluble material applied to the leaves; sugar cane is no exception. Urea, tagged with N15,\*\*\* was sprayed on a large cane plant growing in a normal culture solution. Eight good leaves received the urea and were gathered for analysis as they aged and dropped off. Eight weeks after spraying, when all the old leaves were replaced by new ones, the plant was harvested and subdivided for analysis.

The single spray introduced very appreciable amounts of nitrogen into the plant. For the whole plant, the tagged nitrogen was four per cent of the total. However, much of it remained in the sprayed leaves, in which the N15 was 15

\* Respectively, Principal Physiologist and Biochemist, and Assistant Biochemist, Experiment Station, HSPA.

\*\* The authors are indebted to collaborators Alfred O. C. Nier and John Saari, University of Minnesota, for permission to use mass spectrograph data before publication of final papers.

\*\*\* We are indebted to Dr. R. P. Humbert for having arranged with E. I. du Pont de Nemours for the synthesis of tagged urea.

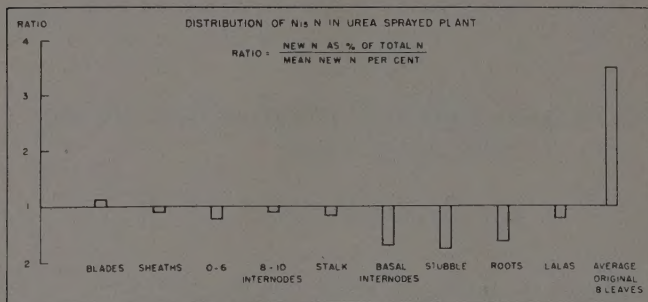


Figure 1

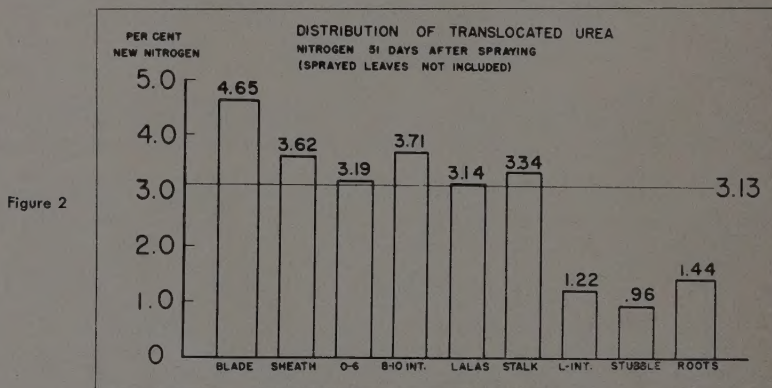


Figure 2

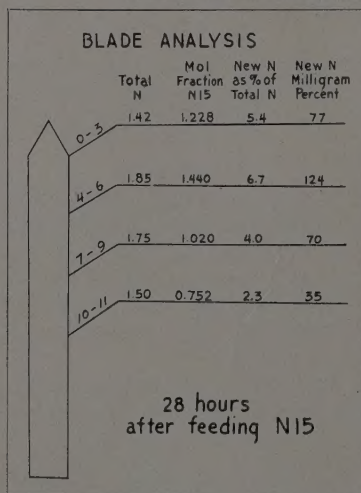


Figure 3

per cent of the total. The very uneven distribution throughout the plant is shown in Figure 1. The ratio of the N<sub>15</sub> in each part to the N<sub>15</sub> of the whole plant (4 per cent) is shown. The original eight leaves were  $3\frac{1}{2}$  times the mean value. Figure 2 shows the distribution in the rest of the plant. The deficiency in the roots, stubble and bottom internodes indicates a limited circulation of nitrogen.

Since our first N<sub>15</sub> feeding in 1948, seven experiments have been completed and others are in progress. From the very first it has been clear that no part of the plant is mature and sealed off from the circulatory system. Within a week after N<sub>15</sub> ammonium sulfate was added to the nutrient solution, every chemical

fraction studied contained N<sub>15</sub>. Even the protein in the oldest leaf and in the mature internodes had exchanged as much as 10 per cent of its old nitrogen for new.

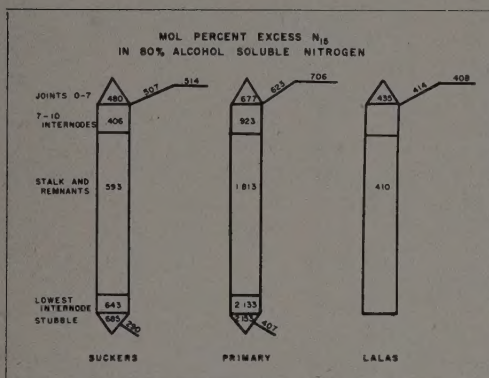


Figure 4

and 6 which are already richest in nitrogen. This may be interpreted as meaning that they are in the stage of maximum activity and that their nitrogen content is the result rather than the cause of this activity. Nitrogen flows to places of metabolic demand and not to a nutritional vacuum, as shown by gross analysis.

When the above plant had taken up the entire dose of N<sub>15</sub>, as it did in one week, it was returned to a culture solution of ordinary nitrogen. After 90 days of summer weather, three large suckers had budded and grown to a combined size greater than the primary stalk. There were also four lalas weighing two-thirds as much as the primary, although the primary had continued its normal growth.

Figure 4 shows the distribution of N<sub>15</sub> expressed as mol fraction. All of the N<sub>15</sub> was in the primary at first, since the suckers and lalas developed after the feeding. The suckers have their own root systems, yet they are rich in N<sub>15</sub> due to a general nitrogen circulation. At harvest, the N<sub>15</sub> distribution was 62 per cent in primary, 31 per cent in suckers and seven per cent in the lalas.

The lalas, which have no roots of their own, have about the same percentage of N<sub>15</sub> as do the suckers, although they are attached directly to the primary stalk which is several times as rich in N<sub>15</sub>.

Turning now from N<sub>15</sub> studies to the usual analytical methods, some fresh tissues were blended in 80 per cent alcohol while others were dried and ground in a Wiley Mill for moisture and total N determination.

The distribution of alcohol-soluble N in an eight-month old cane plant is shown in Figure 5. In well-fed plants, the soluble N is high in the basal joints and reaches a minimum at about the 7 to 10 internodes. For this reason, the 8-10 internodes were arbitrarily chosen for a study of intra-plant ratios of nitrogen levels. Figure 6 shows the great sensitivity of basal soluble N to nitrogen supply, and Figure 7 shows the same sensitivity as the available nitrogen supply diminishes with age.

The soluble N of the 8-10 internodes is much more stable. This results in striking changes in ratios between the two points in the plant. To keep the ratios as whole numbers, the larger value is always in the denominator. When the nitrogen contents of the basal and 8-10 internodes are equal, the ratio is unity; when the nitrogen content of the basal internode is greater than that of internodes 8-10,

In Experiment No. 3, a seven-month old plant growing in culture solution was fed tagged ammonium sulfate. Twenty-eight hours later, leaf punches were taken and analyzed for total and heavy nitrogen. The 11 good green leaves were divided into the four age groups shown in Figure 3.

Apart from the rapidity of uptake of this newly-fed N<sub>15</sub>, the most striking point seems to be that it is not the youngest expanding leaves which have received the most, but leaves 4, 5

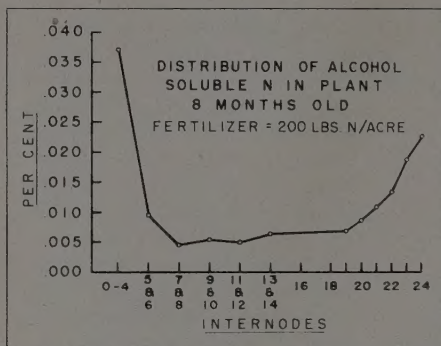


Figure 5

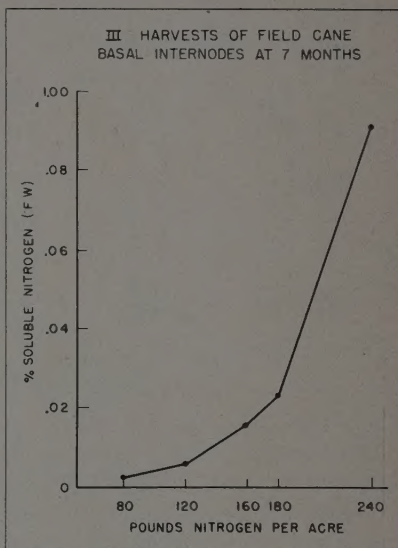


Figure 6

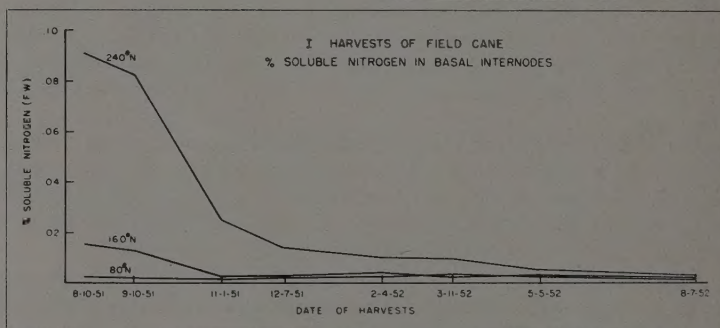


Figure 7

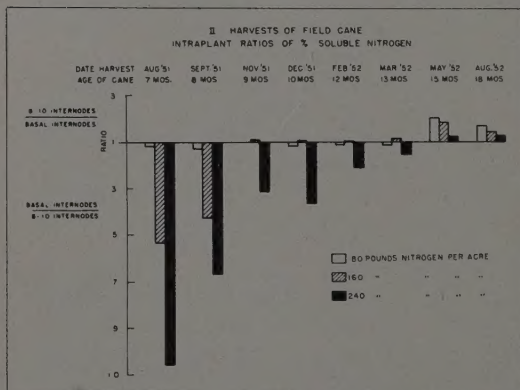
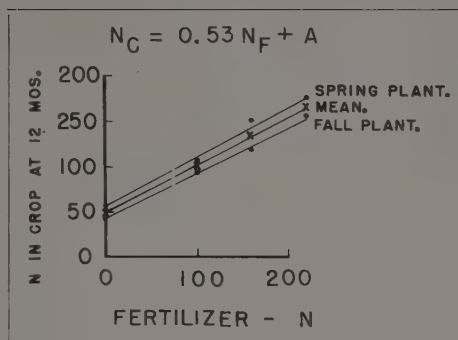
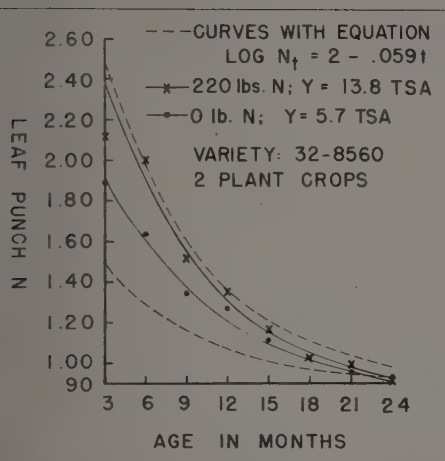


Figure 8



At left Figure 9  
 Above Figure 10

ratios fall below the line; when nitrogen content in internodes 8-10 is greater than in the basal internodes, the ratios are shown above the line. Well-fed plants have basal values well above the 8-10. But as starvation sets in, the basal internode is depleted of soluble N and internodes 8-10 become correspondingly richer. This shows up well in Figure 8. The 160-pound plots are well depleted at nine months, while the 240-pound plots show considerable available N through 13 months.

While the above changes are taking place in the stalks, leaf punch nitrogen values are declining with age according to a smooth logarithmic curve. This is illustrated in Figure 9, the data of which are taken from a paper by Borden (1). The *nitrogen decay curves* fit well into the general equation  $\text{Log } N_t = 2 - .059t$  where  $N_t$  is the leaf punch N at any time,  $t$ , expressed as per cent of the nitrogen value at zero time. A value of 0.9 per cent N is assumed as the lowest to be found in a functioning leaf.

The steady decline of nitrogen in the plant shown in the nitrogen decay curve is due to reduced intake, dilution by growth, and loss through the discarded leaves. Table 1 gives the per cent N in standard leaf punch and total N content per leaf for the top dead leaves taken from plots which had received 100 and 200 pounds of N at ratooning eight months earlier. The losses per acre per month are estimated for an assumed 50,000 stalks dropping three leaves per month. Nitrogen losses through this channel are more or less proportional to the level of nitrogen fed.

The relationship between nitrogen applied as fertilizer and the amount used by the sugar cane crop is shown in Figure 10. The N recovered in the crop ( $N_C$ ) is equal to 53 per cent of the N applied in the fertilizer plus available N in the unfertilized plots. These calculations are also based on data of Borden (1).

TABLE 1. DEAD LEAF ANALYSIS

N Losses, Age 8 Mos.			
N Added Lbs.	Leaf Punch %	N Per Dead Leaf Mg	N Lost Per Mo. Lbs.
100.....	1.20	9.5	3.14
200.....	1.73	15.0	4.95

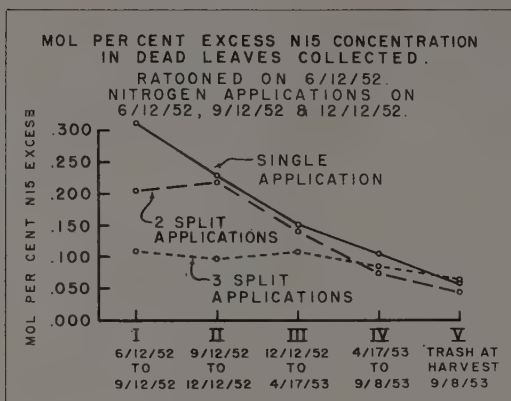


Figure 11

N15 has also been used in a recent study of nitrogen recovery from fertilizer. Ammonium sulfate containing 1.01 atom-per cent excess N15 was fed to ratooned stools of variety 37-1933 at Makiki. The treatments were:

- (1) all fertilizer in single application.
- (2) split applications at zero time and at three months.
- (3) split applications at zero time, three months and six months.

To follow the uptake of fertilizer N and available soil N, the dead leaves were gathered in quarterly periods. The results in Figure 11 show that all the stools were taking up the same amount of non-fertilizer N from the soil. This was diluting the fertilizer N in exact proportion to the amounts being added. The approximate percentages of plant nitrogen coming from the fertilizer during the first three months were 30 per cent, 20 per cent, and 10 per cent from the three treatments. At 15 months of age, the effect of time of application was gone. This may help explain why little difference can be seen between single and split applications when the total spread is only six months and the crop age 18 to 24 months.

Table 2 gives the results of another study of effect of time of fertilizer application. The Makiki plots were fertilized at the same total nitrogen level (300 lb/A) but the applications were as follows: with seed, 100 lbs., 200 lbs. and 300 lbs.; at six months of age, 200 lbs., 100 lbs. and 0 lbs.

TABLE 2. EFFECT OF TIME OF APPLYING FERTILIZER

Plant 4/31/52 Add N	Leaf Punch %	Total N in plant G. at 6 months	Fresh Wt. G.	
100#.....	1.39	0.85	1456	
200#.....	1.64	1.67	1728	
300#.....	1.76	1.75	1887	
<hr/>				
10/31/52 Add N	Total N	at 12 months		
200#	300#.....	1.77	2.35	2015
100#	300#.....	1.69	2.10	2408
0#	300#.....	1.78	2.58	2185

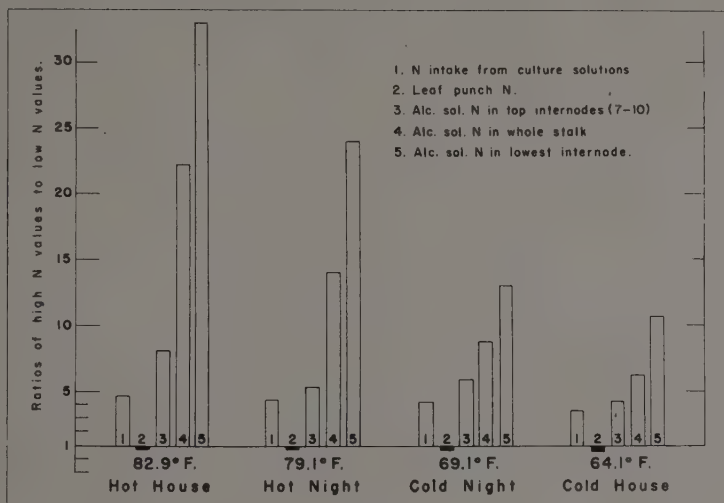


Figure 12

The analyses at age six months, before the second application, show the expected effects of the three amounts of fertilizer. Analyses at 12 months show no great differences. Therefore, it would be reasonable to expect that a spread of six months in nitrogen application would not greatly affect the second season's growth.

### EFFECT OF CLIMATE

Climatic effects are of sufficient magnitude that many analytical values must be corrected for season and local climate. Figure 12 summarizes the results of one experiment with variety 37-1933 in water culture exposed to different temperatures in the climate houses at Makiki. Two levels of nitrogen were fed, one five times the other. The solutions were changed when the high-nitrogen pots in the hot house ran out of N. The ratio of nitrogen uptake in this house was therefore five to one. But in the cold house, nitrogen uptake was reduced 36 per cent so that the nitrogen was not exhausted from the high-N pots. The ratio is, therefore, only three to one.

The effects of nitrogen level on leaf punch N is very different from the effects on stalk analysis. The plants were one year old and the high nitrogen had a maturing effect which resulted in lower leaf N in the high N plants. Hence, maturity effects overshadowed effects of nitrogen level. On the other hand, the highly sensitive basal alcohol-soluble N exaggerated the effects of high-N feeding to several times the average for the plant as a whole.

More recent experiments in which root and air temperatures were separately controlled show the effects of supply and demand on leaf punch nitrogen. Culture solutions carried two levels of nitrogen which resulted in average L P N values of 2.01 per cent and 1.75 per cent. The spread of the high-N values was 1.4 per cent to 2.6 per cent. The relation of these values to air and root temperature is pictured in Table 3. Low root temperature with high air temperature results in nitrogen deficiency in the leaves (30 per cent below average), while hot roots and cool leaves gorge the leaves with N (30 per cent above average).

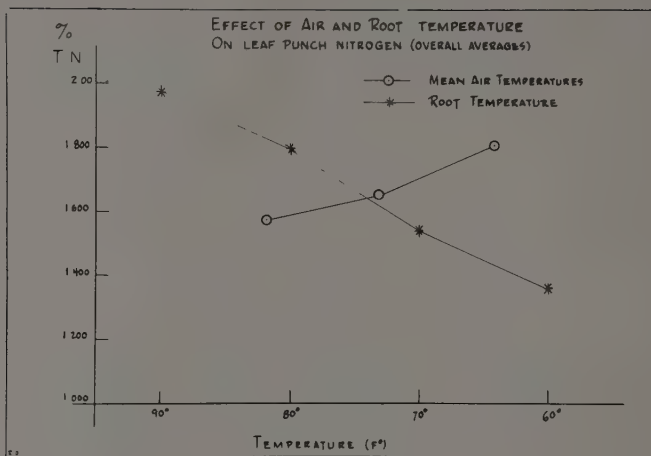


Figure 13

These effects are illustrated in another way in Figure 13. Falling root temperatures lower leaf N while falling air temperatures have the reverse effect.

TABLE 3. RELATION OF HIGH N VALUES TO AIR AND ROOT TEMPERATURES

Variety: 37-1933			
Air Temperature	90°	77°	64°
Hot.....	2.0	2.0	1.4
(+9°).....	(0)	(0)	(-30)
	2.2	2.4	1.4
Makiki....	(+10)	(+20)	(-30)
Cold.....	2.4	2.6	1.7
(-9°).....	(+20)	(+30)	(-15)
Leaf punch nitrogen of young plants growing in 12 climates. Figures in parentheses give percentage deviation from the average.			
Average for high N plants = 2.01% (1.4-2.6)			
" " low N " = 1.75% (1.4-2.0)			

To conclude, the above experiments give evidence that in the sugar cane plant nitrogen is in a state of flux, being moved in a general circulatory system to all parts of the stool; old nitrogen is exchanged for new in every tissue of the plant. The analysis of any single part of the plant cannot give a clear picture of the nitrogen situation since the concentrations in the different parts are changed in relation to one another by temperature, age, nitrogen supply, and other factors. It may well be that the ultimate solution to the problems of foliar diagnosis will be found through intra-plant gradients rather than by the analysis of any one tissue.

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1. Borden, R. J. Hawaiian Planters' Record 49, 259-312 (1945). 52, 1-51 (1948).

## PART II: POTASSIUM

GEORGE O. BURR AND T. TANIMOTO\*

### INTRODUCTION

In the general study of essential nutrients in sugar cane, considerable attention is being given to potassium. In the first experiments described below, consideration is given to the use of rubidium as a tracer for potassium. The remainder of the discussion concerns the effect of the level of nutrient potassium upon the concentration of potassium in the tissues.

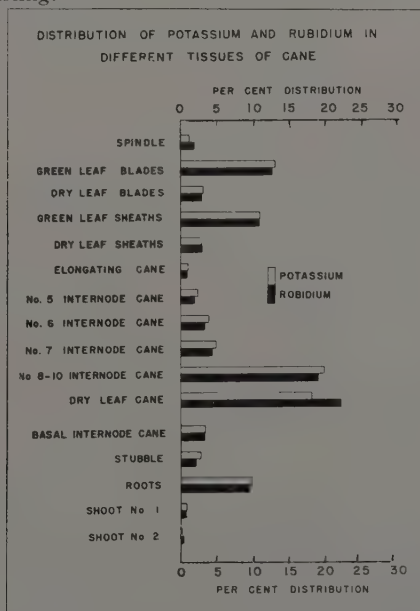
### RUBIDIUM AND POTASSIUM

Radioactive potassium (K42) has such a short half-life (12.44 hours) that it is of little use in most nutrition experiments with sugar cane. Experiments can not be extended much beyond four days.

However, rubidium has a very good radioactive isotope (Rb86) with a half-life of 19.5 days and a good beta ray for Geiger counting. It seemed of interest, therefore, to find out whether Rb concentrations in plant tissues follow the K levels.

In the first experiment, healthy sugar cane plants 4½ months of age were fed a dose of Rb86 via the culture solution. After one week, when most of the Rb had been absorbed, the plant was returned to the normal Rb-free culture solution. Two months later the plants were harvested, divided into many anatomical parts, and analyzed for K and Rb. Potassium was determined with a flame photometer\*\* and the Rb86 by Geiger counting.

Figure 14



\* Respectively, Principal Physiologist and Biochemist, and Associate Biochemist, Experiment Station, HSPA.

\*\* We are indebted to the Department of Chemistry for these analyses.

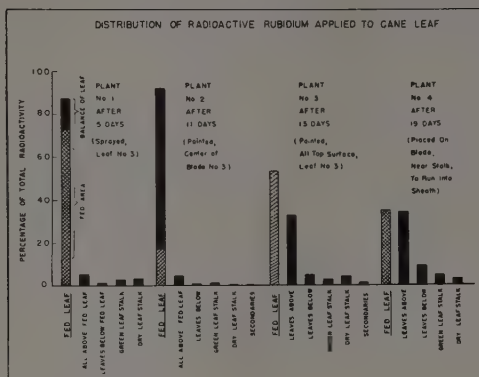
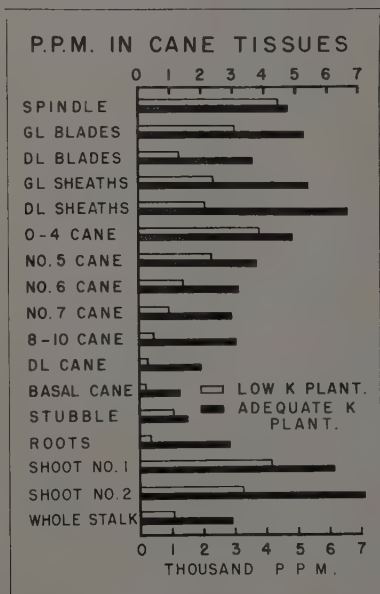


Figure 15

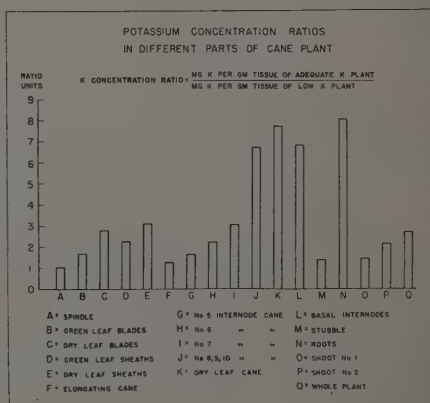
Figure 14 summarizes the results expressed as per cent distribution of the two elements. Two conclusions may be drawn from the evidence:

- (1) Two months were sufficient for Rb to become well distributed in the growing sugar cane plant; and
- (2) Rb is distributed within the plant in the same proportion as K. Hence, Rb may be used as an index of K distribution.

This relationship between the two elements is of great interest. For some time, it has been suspected that Rb may partially substitute for K as an essential element. Apparently the large difference in their atomic weights does not materially alter their affinities for different tissues. The forces which determine their



At Left Figure 16  
Below Figure 17



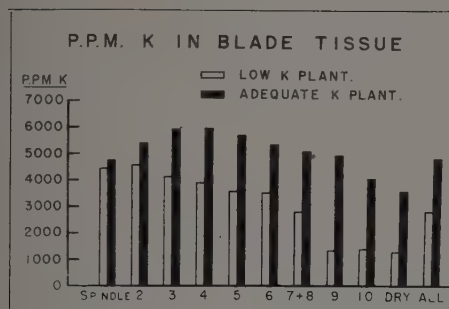


Figure 18

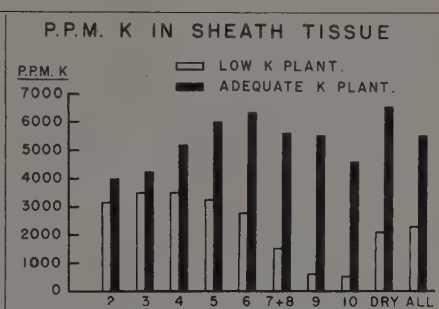


Figure 19

distribution among different tissues apply alike to the two elements. This is all the more remarkable in this case where the total K present was many times the total Rb.

With these findings in mind, the results of the study of absorption of Rb through leaves may be applied to K.\* Figure 15 is largely self-explanatory. The Rb86 solution was applied to a part or all of one leaf. It slowly entered the circulatory stream and went to all parts, including young sprouts. At least 15 days were required for half of the Rb to leave the place of application. When it reached the stalk, most of it turned upward into the young leaves.

#### POTASSIUM CONCENTRATION IN SUGAR CANE TISSUES

In this experiment, one group of plants was transferred to a culture solution low in K until there was a large difference in tissue analyses. Nine weeks was thought to allow sufficient time for the K to reach equilibrium levels throughout the plants. The harvested plants were divided into many anatomical parts and the K was run with the flame photometer. The general results are summarized in Figure 16. The well-fed plant contained three times as much K as did the starved one (bottom of figure). The old cane (DL and Basal) and the roots suffered the greatest depletion while the young growing tissues (spindle and 0-4 cane) maintained almost the full concentration of K.

The ratio of K-well-fed to K-deficient is shown graphically in Figure 17. A ratio of one means that the level of potassium in the tissue was not affected by the fact that this cane is growing in a K-deficient solution. In the case of the old cane and roots, the average difference is magnified about three times.

Figures 18 and 19 picture in greater detail the responses of blade and sheath tissue. Again, the very young tissues are hardly affected by the deficiency, while the response increases steadily down to the 9 and 10 leaves.

These studies have a bearing on the use of tissue analysis as an indicator of nutritional deficiencies. It would appear that the older leaves might be more sensitive indicators than the young ones. The top mature joints, 8-10, also offer promise for this purpose. Further studies along these lines are in progress.

\* The authors are indebted to Dr. A. R. Lamb for this study.

## DISCUSSION

**H. F. Clements:** In the first place, I would like to say that between Dr. Burr's concepts and my concepts, there is this difference about the sensitivity of stem tissue on the one hand, and leaf or sheath tissue on the other. Now, I expect to discuss that very fully tomorrow in my paper, so I don't want to ask about that, but I would like to ask Dr. Burr if he intends to discuss his alcohol-nitrogen more tomorrow in his paper.

**G. O. Burr:** Yes, we will have a considerable amount of the alcohol-soluble data, as well as total nitrogen percentage.

**H. F. Clements:** Then, may I ask this question for a direct answer? Would you outline for the group here what is involved in the actual analytical procedure in getting the alcohol-soluble nitrogen?

**G. O. Burr:** I would be very glad to, even though we are not inclined at the moment to give it great preference over total nitrogen. That will come out in tomorrow's discussion in terms of statistical analyses of field data. It is an exceedingly simple procedure if anyone decides to use it. It has many interesting things about it. The procedure is simply this: for stem, use a meat slicer to slice off thin slices of fresh internode tissue. The fortunate thing about stalk tissues is that they apparently can be cooled, chilled, shipped by air from the various plantations, be cut up the same afternoon, and show no appreciable change. Then we drop the slices into boiling 80 per cent alcohol in a wide-mouth flask to stop enzyme action. They are then transferred to a Waring Blendor and blended for five minutes. The sample is ready for analysis after dilution to volume; the volume includes the tissue. We have no complicated filtrations or anything else. The dilution volume can be such that it's perfect for flame photometer potassium and for total nitrogen in the micro-colorimetric method.

**H. F. Clements:** Thank you very much. There would be the one difficulty then, wouldn't there, for plantations such as our Brewer plantations, that ship their samples from the various plantations to the Onomea lab? Those samples would all have to get in there that same day, wouldn't they, or else stay frozen all the time?

**G. O. Burr:** I think that is one of the factors which will influence us in any recommendations. Even though we may find a slightly higher statistical value for say, a basal soluble alcohol, we are inclined, for practical purposes, to go to total nitrogen, total phosphorus, total K, on dried slices which can be kept indefinitely. Dried stem slices can be shipped anywhere for any of the elements that we are after.

**B. Alexander:** On that one graph you have with the deficient potash compared to the well-fed plant, what is the final response in relation to the stalk and the leaf? Do you have any data on that?

**G. O. Burr:** Right offhand, I don't think of anything that we've done that will come close to an answer. I think that definitely should be done. It would be very rapid in culture solution and be slower in soil and maybe even slower in a leaf spray. I don't know.

**B. Alexander:** Uniformly through the plant or to specific parts of the plant?

**G. O. Burr:** I think it goes in through the roots and then circulates quickly to all parts of the plant, but we have never made a good study of the number of days required. We have for phosphorus, and I could dig out those pictures. Maybe Miss Hartt will give them to you for a single feeding of radioactive phosphate and the time required for even distribution. We have not done that for potassium. We have a feeling rubidium is a good enough indicator for potassium so that we could do a similar precise study with that. A tracer element is so good that you don't have to have a control plant—the plant is its own control. If you would agree with me that rubidium would give a valid test for such a study on potassium, we could come up with that result with high precision in a month or a week, or whatever time it takes to reach equilibrium.

**Walter Naquin:** Dr. Burr, you showed a slide where you had three amounts of nitrogen applied at different times and all reached an equal level at about 15 months. You then translated that into results that Mr. Borden had on his time of application, where you could apply all your nitrogen at one shot or put it on in two or three and not get any measurable differences in yield. Yet, if the timing of application say, at the start of the crop, at one month, and then at three months, gave an increase in growth, wouldn't you expect a greater tonnage of cane with no injury to the juices at harvest from a split application?

**G. O. Burr:** I believe I understand your question clearly. The split application—if each individual application maintains an adequate level in the plant—will never show any decline. If the early splits are too low, then the cane may never recover from having had too little, particularly if those early splits are applied in the summer time or in fast-growing weather. You may never gain back the early losses. Now, if each application is high enough to keep the cane at whatever you decide is an adequate level, and if the early application does not decline below the adequate level before 18 months, the growth picture from 18 months on is slow enough so that you probably will not get a harvest difference. Most of Mr. Borden's studies were between zero time, that is, all on at once, and up to six, and occasionally eight or nine, months. No really late applications, so-called second-season applications, were in any of Mr. Borden's studies, as I recall it. Am I correct in that?

**Walter Naquin:** If you are speaking there of nitrogen levels and not yields.

**G. O. Burr:** No. Look at the ppm of alcohol-soluble nitrogen for that 300-pound application. That's the one we had this morning. At the 300-pound level, we started out with this great luxury

feeding, tremendous luxury feeding, which never completely disappeared. There were still 100 ppm up to 18 months. Now, when we discuss levels tomorrow, you will find that all of this luxury feeding has given no indication that it helped at all. If the analysis has not come down below 100 ppm by the time you're beginning to stop your crop anyway, then 300 pounds early would be just as good as 100 now, and 100 later, and so forth. It might even be better if 100 pounds didn't keep the level up long enough until the next 100 pounds took effect. I'd like to say that I've been talking freely in this seminar, sometimes saying things with considerable positiveness that I don't feel inside, and realizing that future data will have to come along to either confirm or deny these statements. I don't care which way they do. If we can get from these results definite plans for future studies which will confirm or deny what we're saying this morning, then we'll come out with a clearer picture another year.

**Karl Berg:** I have one little comment here. The Station made a study of all the Ewa data about three years ago. Dr. Humbert, I think; did it with one of his young assistants. They took about a dozen of our highest yielding fields, 16-tonners or so, and compared all the Clements crop logs with a dozen of the lowest yielders. The one outstanding difference they found was that the nitrogen curve in the low yielders was lower during the boom stage, say from about two to 10 or 12 months. Do you recall that, Roger?

**R. P. Humbert:** The period was about five to 12 months.

**H. F. Clements:** I would like to ask Dr. Burr another question. I was quite interested in the graph that he showed where they used heavy nitrogen and applied 32 mgs to an irrigation furrow. You showed a loss of something like 30 per cent, or was it a recovery of 30 per cent?

**G. O. Burr:** A recovery of 30 per cent.

**H. F. Clements:** A loss of 70 per cent. At what rate per acre was that nitrogen applied?

**G. O. Burr:** 180 pounds, harvested at 18 months.

**H. F. Clements:** Now then, would that nitrogen continue to be tied up there?

**G. O. Burr:** That nitrogen is now being fed into the ratoons from that crop. The present ratoons are very definitely labeled.

**H. F. Clements:** I wonder how sure, then, Dr. Burr is that the plant is responding to his N15, the same as it would for other forms of nitrogen.

**G. O. Burr:** I would like to say that our N15 is in the same form as the regular nitrogen. It is ammonia nitrogen, bought from Eastman Kodak as ammonium nitrate. Then we dilute it with ordinary ammonium sulfate. Once mixed, there's no distinction between those two ammonium ions. The rich material is diluted to one atom per cent N15, which gives us a precision out to the third decimal place. So we have good, precise data in our studies.

**H. F. Clements:** You're completely satisfied, are you, on your radioactive studies as well as with your heavy nitrogen, that the plant is not affected in any way by any of those materials?

**G. O. Burr:** I can't believe that N15 has had any effect. Many, many studies—precise chemical studies—with enzymes and chemical rates of reactions, and so on, have been made, and everybody is convinced that, except for the mass effect, which of course is exceedingly small, everything else is identical. N15 is certainly the least harmful of all of them. With radioactive materials, you can always say, "Well, when they get inside, what do they do to the cell?" But the users of radioactive material have worked pretty hard on that point and have come up with a general conclusion that if you keep these within certain tracer levels, radiation effects will not invalidate your results. You certainly must not go too high, that's true.

**R. P. Humbert:** I want to comment further on Walter Naquin's question regarding the single applications vs. split applications. The industry as a whole is very definitely at high levels of nitrogen fertilization, and I want to point out the very real danger that we run by applying all of our nitrogen early in case there should be two seasons of poor growing conditions. Certainly split applications will permit an evaluation of what has been used and make it possible to calculate the normal requirements for the remaining months.

**Jack Larsen:** A question for Dr. Burr. Have you found in any of your studies that plant tissues developed with excessive amounts of nitrogen sometimes differ in structure and in sugar-retaining quality from the plants developed under a bare sufficiency or deficiency?

**G. O. Burr:** I'm not sure of your terms, "sugar-retaining quality" or "structure." It has been definitely shown by all the logging people that high nitrogen tissues are what we call "lush" tissue and tend to have high water contents and that sort of thing.

**Jack Larsen:** I wonder if tissues laid down under conditions of excess nitrogen will not be able to harden off and store sugar at the same capacity as those laid down under sufficiency or bare deficiency levels?

**G. O. Burr:** We've made no study of that and I don't recall data of that type available, except that I could make this comment. Putting on 300 pounds of nitrogen at a single dose does not in any way adversely affect the future of the basal joints of that cane. The basal joints are the ones that were laid down at that high nitrogen level, but they come up at the end with just as high juice levels and qualities as upper joints laid down later under lower nitrogen, as the nitrogen is depleted. That, I think, is all I can say at the moment.

**H. F. Clements:** I would like to qualify that, that is, the lower joint doesn't change if it doesn't break.

**G. O. Burr:** I believe you're right. That might be a danger.

**W. W. G. Moir:** I don't think you've given an answer to Mr. Berg over here. I think the correlation is a little bit false insofar as they used winter months to raise that nitrogen for that period on up to 10 or 12 months. I think if you analyze the data, that correlation isn't quite as good as it was.

**G. O. Burr:** It is true, Karl, that when Jim Silva broke down the Waialua data into season and age of cane categories, the relationship you mention was no longer so simple. In analyzing points like that, we have to be very sure that we are not having seasonal effects—confusing seasonal effects with lush growth periods.

# THE ABSORPTION AND DISTRIBUTION OF PHOSPHORUS IN THE SUGAR CANE PLANT\*

HARRY F. CLEMENTS\*\*

As my time permits, I am preparing for publication as a technical bulletin from the University of Hawaii Agricultural Experiment Station, a manuscript dealing with the phosphorus portion of crop-logging. The present paper is somewhat of a preview of that bulletin and because of time limitation must be brief. The objectives are several: to present data showing the phosphorus composition of cane plants growing under conditions of adequate as well as marginal or perhaps inadequate soil supply; to present data showing the composition of cane plants grown in nutrient solution with and without phosphorus; to present data on which the selection of an index tissue can be based; to present formulae standardizing the P Index readings; to present data indicating the adequacy level for guidance in phosphorus fertilization; and finally to present recommendation on phosphate fertilization.

Early in these studies, sugar cane (31-1389) was grown in four blocks at Kailua and four blocks at Waipio. The time of start of each of these blocks was staggered in three-month intervals and each crop was grown through one plant crop and one ratoon cycle. Later, four blocks of 32-8560 similarly staggered with reference to time of start, were grown only at Waipio through one plant and one ratoon cycle.

As it developed, Waipio is an area of fairly high phosphorus availability and Kailua quite low. However, 200 pounds of  $P_2O_5$  as ammophos were applied under the seed at both places. When analytical data which I shall subsequently present were available, it became evident that the Kailua plants might be inadequately provided not only with phosphorus but also with calcium. After harvesting each plot, a furrow was plowed beside each line of cane, and reverted phosphate was applied at the rate of 400#  $P_2O_5$  per acre. In addition, the first applications of nitrogen were provided as calcium nitrate. The Waipio ratoons of 31-1389 were not given phosphate at all because of their high tissue levels. Also, neither the plant nor ratoon cycles of 32-8560 were given phosphate fertilization.

At intervals of approximately one month, samples of five representative stalks, including tops, were *selected* and removed from each block of cane at each place, separated into various parts as indicated in the table, weighed, dried, ground, and stored for analysis. Considering only these field blocks, some 8,000 phosphorus analyses were made.

For presentation at this seminar I have selected four such sets of phosphorus compositional data, (Tables 1-4) all representing the same variety, 31-1389, but representing two locations, Waipio and Kailua, and at each place a plant and a ratoon crop. Usually one day separated gathering the samples at each place.

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TABLE 1. PHOSPHORUS COMPOSITION (P = % DRY WT.) OF SUGAR CANE (31-1389)

	Plant Crop (Plot C) Waipio																		
	1939																		
Sampling Dates Age (Months)	Mar. 23 1.8	Apr. 20 2.8	May 25 3.9	June 26 5.0	July 22 5.8	Sept. 1 7.2	Sept. 29 8.1	Oct. 27 9.0	Nov. 25 9.9	Dec. 26 11.0	Feb. 1 12.2	Mar. 8 13.3	Apr. 13 14.6	May 17 15.7	June 21 16.8	July 26 18.0	Aug. 30 19.1	Oct. 4 20.2	Nov. 8 21.4
Old Sheaths.....			.038	.043	.050	.047	.051	.050	.051	.046	.050	.044	.036	.055	.058	.055	.053	.044	.043
" Blades.....			.100	.085	.102	.084	.089	.060	.086	.096	.092	.079	.068	.117	.075	.083	.079	.083	.075
Young Sheaths.....	.117	.070	.065	.090	.095	.083	.076	.080	.098	.090	.095	.068	.065	.093	.103	.120	.113	.085	.068
P-Index.....	.131	.078	.074	.101	.106	.092	.086	.089	.112	.101	.112	.080	.077	.112	.120	.146	.129	.098	.080
Young Blades.....	.225	.154	.115	.119	.146	.131	.129	.144	.140	.138	.117	.104	.088	.154	.105	.121	.129	.121	.100
Spindle Cluster.....	.256	.175	.167	.208	.206	.200	.181	.219	.179	.192	.183	.200	.150	.196	.179	.200	.179	.146	.100
Spindle Cluster.....	.256	.175	.167	.208	.206	.200	.181	.219	.179	.192	.183	.200	.150	.196	.179	.200	.179	.146	.100
Meristem.....	.663	.563	.613	.656	.631	.581	.688	.625	.606	.700	.588	.725	.525	.413	.525	.500	.675	.525	.525
Elongating Cane.....			.331	.281	.281	.288	.350	.363	.281	.513	.413	.338	.293	.231	.338	.348	.338	.338	.338
Green Lf Cane.....			.096	.059	.074	.084	.061	.079	.085	.093	.105	.065	.058	.085	.125	.133	.130	.080	.068
Top Internodes.....					.040	.058	.046	.053	.053	.068	.085	.055	.045	.045	.095	.093	.058	.058	.048
17th 3 ".....																		.063	.058
16th 3 ".....																		.063	.058
15th 3 ".....																	.053	.070	.055
14th 3 ".....																.065	.065	.055	.058
13th 3 ".....														.053	.073	.063	.058	.060	.058
12th 3 ".....														.065	.065	.068	.058	.073	.058
11th 3 ".....														.055	.068	.068	.063	.063	.048
10th 3 ".....												.065	.055	.059	.073	.065	.065	.065	.048
9th 3 ".....													.055	.063	.063	.063	.063	.063	.050
8th 3 ".....													.060	.060	.063	.058	.048	.060	.060
7th 3 ".....														.058	.063	.058	.055	.055	.055
6th 3 ".....									.055		.068	.055	.058	.063	.053	.058	.050	.058	.063
5th 3 ".....									.046	.050	.058	.058	.063	.051	.058	.060	.050	.058	.063
4th 3 ".....									.045	.049	.068	.053	.068	.053	.060	.055	.058	.063	.070
3rd 3 ".....						.060	.045	.063	.054	.044	.058	.088	.088	.083	.070	.068	.068	.080	.078
2nd 3 ".....						.058	.060	.083	.066	.108	.098	.103	.128	.123	.090	.098	.090	.098	.103
1st 2 ".....				.040	.060	.090	.080	.076	.093	.117	.138	.138	.183	.204	.117	.100	.093	.103	.113

TABLE 2. PHOSPHORUS COMPOSITION (P = % DRY MATTER) OF SUGAR CANE (31-1389)

1941		Ratoon Crop (Plot C) Waipio																
Jan.	Feb.	Mar.	May	June	July	Aug.	Sept.	Oct.	Nov.	Jan.	Feb.	Mar.	Apr.	May	June	July	Sept.	Oct.
17	22	29	2	6	12	16	20	24	28	3	7	13	17	23	26	31	14	9
Age (Months)	2.9	4.1	5.2	6.4	7.5	8.7	9.8	10.9	12.1	13.3	14.4	15.5	16.7	17.9	19.0	20.2	21.3	22.4
Old Sheaths.....	.150	.075	.080	.073	.058	.053	.053	.060	.058	.053	.043	.040	.039	.045	.048	.048	.048	.041
"  Blades.....	.188	.117	.092	.090	.104	.092	.096	.096	.104	.100	.108	.060	.055	.065	.083	.073	.070	.068
Young Sheaths.....	.142	.163	.118	.133	.125	.142	.130	.154	.130	.146	.090	.067	.080	.129	.133	.125	.078	.058
P-Index.....	.162	.186	.137	.151	.139	.159	.164	.143	.166	.141	.160	.098	.073	.090	.141	.149	.093	.071
Young Blades.....	.213	.167	.121	.133	.150	.150	.158	.167	.154	.133	.073	.088	.088	.117	.138	.129	.100	.100
Spindle Cluster.....	.275	.250	.192	.204	.244	.213	.238	.204	.229	.208	.208	.154	.154	.213	.213	.204	.158	.150
Meristem.....	.825	.725	.675	.600	.750	.750	.725	.600	.725	.613	.375	.500	.450	.613	.650	.375	.388	.300
Elongating Cane.....	.650	.575	.363	.625	.338	.475	.476	.475	.388	.525	.183	.123	.117	.288	.450	.375	.288	.185
Green Lt Cane.....	.375	.219	.158	.103	.103	.080	.105	.080	.103	.103	.075	.050	.073	.093	.073	.048	.110	.085
"  Internodes.....			.080														.085	.070
17th ".....																	.090	.095
16th ".....															.070	.058	.100	.088
15th ".....														.098	.080	.065	.088	.093
14th ".....														.118	.090	.070	.093	.098
13th ".....														.110	.093	.070	.075	.100
12th ".....														.085	.095	.068	.083	.095
11th ".....												.060	.080	.085	.110	.095	.073	.085
10th ".....											.070	.083	.083	.108	.083	.073	.083	.085
9th ".....										.095	.073	.060	.075	.100	.103	.073	.078	.110
8th ".....									.073	.093	.078	.060	.075	.100	.103	.073	.078	.110
7th ".....								.109	.083	.090	.060	.053	.078	.098	.105	.068	.083	.100
6th ".....							.070	.095	.078	.100	.075	.068	.085	.115	.113	.083	.093	.110
5th ".....							.068	.105	.083	.110	.085	.068	.093	.121	.129	.095	.110	.120
4th ".....							.073	.105	.085	.110	.108	.118	.115	.142	.158	.103	.133	.133
3rd ".....					.093			.073	.085	.110	.108	.118	.115	.142	.158	.103	.133	.133
2nd ".....					.083	.103	.103	.128	.105	.143	.135	.093	.146	.152	.200	.133	.163	.161
1st ".....			.108	.070	.103	.118	.103	.150	.142	.148	.169	.200	.163	.250	.250	.138	.183	.194



TABLE 4. PHOSPHORUS COMPOSITION (P = % DRY WT.) OF SUGAR CANE (31-1389)

Plot RC—Ratoon Crop at Kailua																			
Sampling Dates.....	Jan. 18	Feb. 22	Mar. 29	May 2	June 6	July 12	Aug. 16	Sept. 20	Oct. 25	Nov. 29	Jan. 3	Feb. 7	Mar. 13	Apr. 17	May 23	June 27	Aug. 9	Sept. 15	Oct. 20
Age (Months).....	1.7	2.9	4.1	5.2	6.3	7.5	8.7	9.8	10.9	12.1	13.2	14.4	15.5	16.7	17.9	19.0	20.4	21.3	22.5
Old Sheaths.....		.070	.083	.055	.040	.035	.039	.039	.053	.048	.050	.040	.045	.035	.047	.055	.044	.048	.055
" Blades.....		.113	.129	.095	.065	.075	.088	.079	.083	.092	.092	.065	.065	.060	.075	.078	.085	.088	.108
" Young Sheaths.....	.142	.113	.095	.063	.048	.073	.060	.080	.083	.088	.070	.058	.063	.053	.075	.075	.085	.083	.118
" P-Index.....	.157	.124	.106	.072	.057	.080	.065	.087	.088	.094	.078	.062	.065	.060	.089	.080	.089	.093	.119
" Young Blades.....	.208	.117	.146	.108	.092	.100	.108	.121	.142	.129	.117	.100	.088	.083	.092	.092	.117	.129	.146
" Spindle Cluster.....	.213	.183	.175	.121	.167	.150	.179	.213	.188	.163	.153	.158	.158	.133	.146	.167	.167	.175	.188
" Spent Stem.....	.250	.150	.183	.120	.183	.168	.188	.238	.218	.207	.202	.233	.250	.225	.248	.258	.238	.243	.325
" Green Lf. Canes.....	.250	.150	.183	.120	.183	.168	.188	.238	.218	.207	.202	.233	.250	.225	.248	.258	.238	.243	.325
" Green Lf. Canes.....	.250	.150	.183	.120	.183	.168	.188	.238	.218	.207	.202	.233	.250	.225	.248	.258	.238	.243	.325
" Top Internodes.....	.250	.146	.129	.070	.063	.075	.058	.083	.063	.075	.058	.070	.083	.065	.108	.095	.088	.118	.120
" 13th 3 ".....				.040		.033	.026	.028	.045	.043	.053	.036	.064	.065	.093	.070	.058	.070	.078
" 12th 3 ".....																.073		.060	.068
" 11th 3 ".....																	.075	.060	.085
" 10th 3 ".....																.095	.100	.085	.088
" 9th 3 ".....															.095		.123	.100	.078
" 8th 3 ".....												.045	.063	.068	.098	.108	.099	.070	.078
" 7th 3 ".....													.055	.058	.083	.093	.063	.063	.063
" 6th 3 ".....													.051	.063	.083	.075	.063	.063	.058
" 5th 3 ".....							.029		.035	.034	.050	.048	.048	.063	.073	.060	.070	.063	.068
" 4th 3 ".....								.033	.036	.039	.044	.045	.056	.060	.063	.060	.075	.085	.080
" 3rd 3 ".....							.033	.039	.043	.038	.044	.045	.056	.060	.063	.060	.075	.085	.080
" 2nd 3 ".....					.048	.041	.056	.043	.038	.043	.050	.064	.068	.071	.113	.108	.113	.100	.093
" 1st 3 ".....			.090	.063	.085	.075	.100	.075	.056	.068	.065	.075	.098	.121	.188	.200	.075	.125	.115

The various parts of the plant contain a rather characteristic level of phosphorus. Comparing the two plant crops, Tables 1 and 3, it is evident that the Kailua plants are growing under a much lower available supply of phosphorus than the Waipio counterparts. The meristem contains the highest amount of P, followed by the elongating cane, then the spindle cluster, young blades, etc. with the mature cane containing least. As the tissues mature, they contain less and less phosphorus; for example, in Table 1, the old sheaths contain less phosphorus even than the mature cane. In Table 3, however, which represents data from Kailua cane, this is not true. Here the cane shows the lowest phosphorus content. In general, the ratoons (Tables 2 and 4) contain higher levels than the previous plant crop.

TABLE 5. POUNDS OF PHOSPHORUS REMOVED BY CANE  
(per ton of net cane)

Plot	Waipio 32-8560			Kailua 31-1389		
	#P	#P <sub>2</sub> O <sub>5</sub>	#P <sub>2</sub> O <sub>5</sub> removed per acre (net cane)	#P	#P <sub>2</sub> O <sub>5</sub>	#P <sub>2</sub> O <sub>5</sub> removed per acre
A	.42	0.96	113	.23	0.53	42
B	.38	0.87	111	.18	.41	33
C	.40	0.92	130	.16	.37	38
D	.36	0.82	109	.16	.37	21
RA	.44	1.01	78	.45	1.03	52
RB	.34	.78	84	.42	0.96	..
RC	.40	0.92	106	.40	0.92	..
RD	.40	0.92	99	.34	0.78	..

The total amount of phosphorus removed by a crop is determined, of course, not only by the size of the crop but by the level of phosphorus contained by the crop. In Table 5 are shown the amounts of phosphate removed by crops of 32-8560 and also by Kailua crops of 31-1389. On the basis of "pounds P" per ton of cane, the Kailua ratoons compare rather favorably with the Waipio ratoons. The Kailua plant crops are, however, very low. On the basis of P<sub>2</sub>O<sub>5</sub> removed by crops of net cane per acre, the range is from 21 pounds for Plot D at Kailua to 130 pounds for Plot C at Waipio. This table illustrates rather strikingly the fallacy so common in the industry that putting on phosphate even if it isn't needed is all right since then it is an investment for the future. If the phosphate is available, the plant absorbs much more than it needs.

#### COMPOSITION OF SUGAR CANE PLANTS GROWN IN CULTURE SOLUTION

In Table 6 are data comparing the phosphorus content of sugar cane (31-1389) grown in a complete nutrient solution (Series X) with sugar cane which was grown from germination to about three months of age in full nutrient and transferred October 1 to a solution free of phosphate. Although other treatments were also involved, only these two are given in this paper. It is rather striking that growth continues as well as it did in Series A, but by July 9, the plants were so near to death that on that date phosphate was applied to the solution again. The composition shown in Table 6 for Series A, October 5, is thus a measure of the responsiveness of the tissues to treatment. You will note that the P-Index jumped from .028 to .181, an increase of between six and seven times while the cane samples only about doubled.

TABLE 6. PHOSPHORUS COMPOSITION (P = % DRY WT.) OF SUGAR CANE (31-1389)  
Grown in Culture Solution with and without Phosphate

Sampling Dates Age.....	1942									
	Series X					Series A				
	10/1	10/30	11/27	12/26	1/22	2/19	3/19	7/9	10/5	
	2.0	3.0	3.9	4.9	5.7	6.6	7.6	11.3	14.1	
Old Sheaths.....	.115	.063	.060	.063	.053	.050	.041	.063	.120	
" Blades.....	.163	.138	.125	.123	.133	.100	.073	.088	.118	
Young Sheaths.....	.128	.118	.110	.118	.098	.088	.073	.086	.109	
P-Index.....	.150	.135	.125	.138	.113	.103	.086	.113	.135	
Young Blades.....	.188	.167	.138	.167	.096	.129	.113	.129	.148	
Spindle Cluster.....	.210	.210	.218	.218	.160	.178	.163	.171	.186	
Peristeme.....	.200	.238	.208	.213	.150	.175	.163	.175	.186	
Green Lf Canes.....	.230	.238	.263	.250	.226	.267	.233	.243	.325	
Green Lf Canes.....	.230	.238	.263	.250	.226	.267	.233	.243	.325	
Top Internodes.....	.133	.095	.085	.090	.060	.068	.060	.098	.088	
17th 3 ".....		.060	.048	.055	.055	.050	.056	.080	.063	
16th 3 ".....									.075	
15th 3 ".....									.068	
14th 3 ".....									.058	
13th 3 ".....									.065	
12th 3 ".....									.083	
11th 3 ".....								.075		
10th 3 ".....								.100	.070	
9th 3 ".....								.093	.070	
8th 3 ".....								.100	.073	
7th 3 ".....								.100	.078	
6th 3 ".....								.105	.078	
5th 3 ".....								.117	.078	
4th 3 ".....							.059	.058	.121	
3rd 3 ".....						.059	.065	.068	.133	
2nd 3 ".....				.068	.050	.093	.120	.138	.146	
1st 3 ".....	.142	.080	.060	.065	.053	.065	.070	.080	.078	
Roots.....	.167	.175	.121	.167	.154	.149	.163	.163	.158	
Dead Lf Blades.....		.079	.068	.065	.053	.064	.043	.053	.063	
" Lf Sheaths.....		.037	.035	.038	.031	.030	.024	.038	.033	

One striking characteristic of plants which are deficient in a nutrient is that as some of the tissues mature, the nutrient is given up and moves on to the more active areas. Thus, comparing the composition of the old sheaths and old blades with the young sheaths and blades, one sees that the old tissues contain only about half as much phosphorus as their young equivalents. The old blades in Series X have given up much of their phosphorus and yet as they died they gave up still more, as shown by the fact that the dead sheaths and blades contain about half as much as the old living sheaths and blades. And yet, these dead leaves coming from a solution adequately supplied with phosphorus contain about as much phosphorus as the young sheaths grown in P-deficient solutions.

The same situation is shown by the cane internodes. The composition of the internodes in Series A is only about one-tenth that of Series X. It is of interest that when phosphate was again applied to the deficient solution that the tops built up their content much faster than the stalks.

### SELECTION OF THE P INDEX

Now, if we grant that phosphorus, before it affects the welfare of the plant, must be within its tissues, and that the distribution within it is determined by the activity of the tissue, then it behooves us first to inquire into the functions which phosphorus serves, and then select the phosphorus level of a particular tissue to serve as the guide to the phosphorus nutrition of the plant.

Although phosphorus occurs in plant tissue as part of certain proteins and certain lipoidal materials, its most common form appears to be in the inorganic state as phosphate. In this state, it takes an active part not only in the photosynthetic activities of the green leaves, but it must also be present before the energy locked up in glucose can be released in respiration not only for growth in the meristem and elongating cane, but wherever transformations occur. Thus, as the simple sugars are transformed into sucrose, phosphate is required to be present. In sugar cane as with other plants, phosphorus must be present in high amounts in the meristems of the stems and roots and elongating cane, because here protoplasm for growth is formed. It must be present in adequate amounts in the green leaves of the plant because it takes part in photosynthesis, and it must also be present in the stalk, although here the evidence shows that it can be present in very small amounts and still be adequate. Now, in assessing the adequacy of the phosphorus level, we must be sure that adequate levels are present in all these parts. We have the choice of analyzing all of these tissues individually or seeking an Index tissue which correlates well with all of these tissues.

The tables already presented together with all the other plots furnish the opportunity to make such a selection. In Table 7, the correlations of the various tissues with an index potential and the green top, whole plant, growing stem, etc. are shown from the data of the water culture series.

All of the correlation coefficients shown in Table 7 are highly significant. As an evaluation summary, the column at the extreme right of the table shows the average percentage variation accounted for. The P-Index, which is the phosphorus content of the young sheaths expressed on a sugar-free dry weight basis, and the young sheaths are definitely the best index tissues. The old sheaths are the poorest. It is also apparent that were mature cane used, its correlations with the meristem, green leaves, etc. would also be poor.

TABLE 7. CORRELATIONS BETWEEN THE PHOSPHORUS CONTENT OF CERTAIN POSSIBLE INDEX TISSUES AND PLANT PARTS (31-1389)  
(Data from culture solution series) (n = 41)

	Dead leaves	Whole plant	Green top	Mature cane	Growing stem	Ave. % Variation accounted for
Meristem.....	.910	.922	.874	.854	...	79.3
Young Blades.....	.893	.924	.936	.868	.852	80.1
Old Blades.....	.930	.929	.928	.845	.877	80.3
Spindle Clusters.....	.892	.898	.885	.833	.918	78.4
Young Sheaths.....	.939	.954	.968	.893	.900	86.7
P-Index.....	.936	.951	.966	.898	.891	86.3
Old Sheaths.....	.793	.856	.883	.865	.702	67.6
Green Leaf Cane.....	.868	.932	.969	.924	.835	82.2

Now the green leaf cane also shows promise, but its high correlation with the green top may well be the result of its being a substantial portion of the green top. Hence, when the green leaf cane and young sheaths are compared in their correlations with the meristem, the region of greatest growth activity, with young and old blades, the centers of photosynthetic activity, and with the mature cane, the place of storage, the young sheaths are superior in three out of four categories as shown in Table 8. The data are taken from the Waipio and Kailua plots of 31-1389.

TABLE 8. COMPARISON OF GREEN LEAF CANE AND YOUNG SHEATHS  
as Indicators of Phosphorus levels in other parts (n = 263)

	Meristem	Young blades	Old blades	Mature cane
Green Leaf Cane.....	.677	.528	.325	.789
Young Sheaths.....	.795	.792	.522	.615

One other point which needs to be satisfied is which of the tissues is most responsive to the total difference in phosphorus absorption.

In Table 9, the Waipio phosphorus readings are shown for each main tissue as percentages of the corresponding Kailua tissue. These percentages represent the tissue from 3.0 to 17.0 months of age. This approach confirms what we already know, that the green tissues as well as the meristem are the tissues favored by the plant in its distribution of the absorbed phosphorus, and hence even though the Kailua crops are growing with a much lower phosphate nutrition, the phosphorus levels in these two critical plant areas are maintained. Thus, these tissues cannot be used as index tissues. This probably accounts for the confusion which exists that foliar diagnosis is not suited to the phosphorus problem. However, the data are very pointed in showing that the P-index and the various stem tissues show a decided difference in the plant crop, but most important, in the ratoon crop which follows, these tissues seem about equally sensitive. Thus, the P-index relationship is 170 per cent, the green leaf cane 171 per cent and the mature cane 178 per cent. These relationships taken into consideration along with the correlation data shown in Tables 7 and 8 leave no doubt in my mind about the young sheaths being the best tissue for guiding our phosphorus fertilization of sugar cane. Now, of course, in crops other than sugar cane not having the equivalent of the sheath tissue, it would be desirable to base phosphate fertilization on the ratio between the phosphorus level of mature tissues such as stems to the level in a

TABLE 9. WAIPIO AND KAILUA PHOSPHORUS LEVELS—PLOTS C

	Waipio	Kailua	Waipio P as Per cent of Kailua P
<b>Plant Crops</b>			
Old Sheaths.....	.048	.043	112.
Old Blades.....	.088	.089	99.
Young Sheaths.....	.084	.066	127.
P-Index.....	.096	.075	130.
Young Blades.....	.127	.114	111.
Spindle Cluster.....	.188	.151	125.
Green Leaf Cane.....	.082	.058	141.
Mature Cane.....	.071	.040	178.
Meristem.....	.603	.527	114.
Elongating Cane.....	.324	.217	149.
<b>Ratoon Crop</b>			
Old Sheaths.....	.055	.049	112.
Old Blades.....	.088	.089	101.
Young Sheaths.....	.122	.073	167.
P-Index.....	.136	.080	170.
Young Blades.....	.129	.112	115.
Spindle Cluster.....	.198	.165	120.
Green Leaf Cane.....	.137	.080	171.
Mature Cane.....	.098	.055	178.
Meristem.....	.656	.510	129.
Elongating Cane.....	.419	.272	154.

young active tissue such as young leaves or perhaps even better, the meristem.

Because of all this evidence, the P-index for sugar cane is defined as the phosphorus content of the young sheaths (from leaves 3, 4, 5 and 6 counting downward from the spindle leaf as No. 1) expressed on a sugar-free dry weight basis. Although the table does not show the advantage of using the sugar-free dry weight basis, it is used because at times under ordinary plantation conditions, the total sugar levels are so high that a serious distortion in the phosphorus reading would result if the index was not on a sugar-free dry weight basis.

### THE STANDARD P INDEX

Now that we have selected our tissue, the next question to answer is: what is the influence of other factors on the level of phosphorus in the sheath tissue. It is common knowledge that the level of various nutrients in plants grown in the field is affected rather markedly by the vigor of the plant, and also sometimes by other ions, either anions or cations. Hence, during the early stages of work leading to the development of the crop-log, several field experiments were conducted at Kohala Sugar Company and at Waialua Agricultural Company. Three crop-log samples were collected from these plots and analyzed for moisture, total sugars, nitrogen, phosphorus, potassium, calcium and magnesium. Now using the Kohala data with the Waialua data is desirable since, because of severe climatic conditions, Kohala represents an area of low sugar production, while Waialua represents an area of very high sugar production. Although this phase deserves a much more thorough presentation, here, because of time limitations, only a very brief summary can be presented. The relationships of the Waialua and Kohala factors to P levels are shown in Table 10.

The two dominant factors affecting the P index level other than available phosphorus, are clearly sheath moisture and total sugars. Although calcium seems

TABLE 10. PARTIAL REGRESSIONS OF CERTAIN FACTORS  
on the level of the P-index  $n = 743$

Factor	Beta	"t"
Sheath Moisture.....	+ .7142	9.88**
Total Sugars.....	+ .4954	8.80**
K-Index.....	+ .0586	1.00
Ca-Index.....	+ .1170	2.30*
Mg-Index.....	- .0170	.37

\* Significant at 5% level.

\*\* Significant at or beyond 1% level.

to be somewhat correlated with the phosphorus index, it is significant only at the five per cent level. When Ca and Mg are both dropped from the analysis, potassium assumes a highly significant negative relationship which helps to account for some losses of yield due to phosphate fertilization. However, for our purposes, the sheath moisture and total sugars are adequate as factors for use in arriving at a Standard Phosphorus Index (SPI). The equation † which develops for this purpose is:

$$P_2 = P_1 - .004603M_1 - .002715S_1 + .40064.$$

where

$P_2$  = the Standard P Index

$P_1$  = the Actual P Index

$M_1$  = the actual Sheath Moisture level

$S_1$  = the actual total sugar level

Tables were prepared by H. K. Stender showing the whole part of the equation for the whole range of moisture (73-90) and total sugars from 3.0-25.0. Once the analyst has the P-Index, he refers to the table for the appropriate correction factor which he adds if it is positive (black on the table) or subtracts if it is negative (red on the table). The above equation standardizes all the P-Index readings for a moisture content of 81.0 and a total sugar content of 10.24. These values were arrived at as good strong values during the period 6-15 months of age and May through October.

Now the advantage of using the Standard Phosphorus Index (SPI) is that some areas have very high moisture and some varieties have very high tissue moistures, while in other areas severe droughts develop to affect the phosphorus reading. In effect this equation tells what the P-Index would be were conditions normal for growth. The equation will reduce the P-Index in areas of high tissue moisture and increase it in drought areas. In places where irrigation control is good, the readings will be affected only slightly, if at all.

### THE NORMAL LEVEL FOR GROWTH

Now that the P-Index has been selected and standardized, the next point to determine is what is the SPI level beyond which we can be sure we do not need to fertilize and beneath which we do need varying amounts of fertilizer.

*A priori* considerations lead us to surmise that other things being equal we need to make our readings during times of maximum absorption. The actual absorption in pounds per acre appears to parallel the growth rate. The boom stage of growth then is likely to be the best time to measure the success the plant has satisfying its demand for phosphorus. Now for sugar cane, the boom stage in

† I wish to acknowledge with thanks the help given me on this equation by Dr. C. Gregory, Professor of Mathematics at the University of Hawaii.

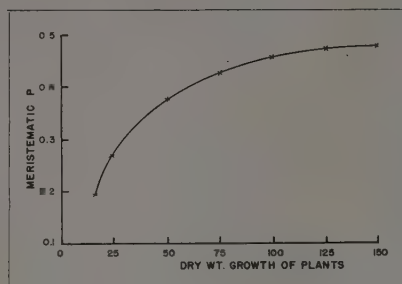


Figure 1

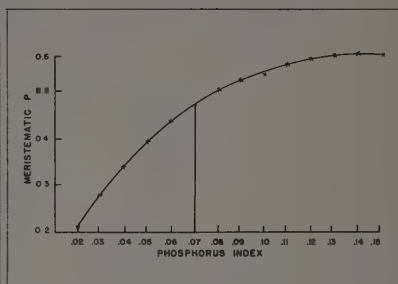


Figure 2

my experience is to be found to occur anywhere between 6-15 months of age during the warmest months of the year, May through October or even into November. If it is possible, it is best to take these readings in August, September, and October, although, of course, to be in the proper age category, this cannot always be done.

Using the growth data taken from the water culture series and correlating them with the actual phosphorus level of the meristem, the curve obtained is as shown in Figure 1.

Growth leveled out at a meristematic P reading of .470. When the P-Index is plotted against the meristem P, .470 in the meristem corresponds to .070 on the P-Index as shown in Figure 2. When the growth in this series is plotted directly against the P-Index, growth has leveled off by the time a P-Index of .085 is reached.

Another way to get at this is suggested by the characteristics already described where the plant moves the phosphate ions from the mature portion to the growing point.

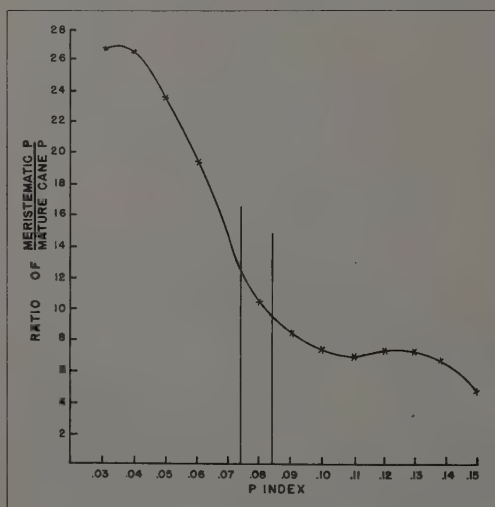


Figure 3

The P-Index values are plotted against the ratio of meristematic P-Mature Cane P, and the curve shown in Figure 3 was obtained. Where the P-Index is very low, the ratio is very high, and contrariwise where the Index is very high, the ratio is low. It again appears that the break occurs in the region of .070 and .085.

When the field grown plants are similarly treated, again the break in the ratios occurs approximately in the area .070 to .085.

Since at .085 ratios have leveled off and since at .070 the levels are beginning to rise sharply, a standard P-Index reading of .080 can be considered as very close to the correct level—above this, increases in yield from phosphate fertilization would not be expected but the farther below this level a crop finds itself the bigger the response would be.

### FIELD EXPERIMENTS

Studies under field conditions were begun in 1943 when fields at Kohala were being logged. Some of the phosphate indexes were below the .080 level regarded then as the tentative normal and many potassium deficiencies were also found. Experiments were set up in several fields, but in Hawi I and Halawa 5 harvest

TABLE 11. HAWI I EXPERIMENT—HARVESTED 8/7/47

	Sheath Moisture	K-Index	P-Index	TSA
K <sub>0</sub> *P <sub>0</sub> *.....	75.5	.96	074	5.49
K <sub>0</sub> P <sub>1</sub> .....	75.6	1.02	082	5.09
K <sub>1</sub> P <sub>0</sub> .....	76.8	2.45	074	7.02
K <sub>1</sub> P <sub>1</sub> .....	76.4	1.89	078	7.49
K <sub>2</sub> P <sub>0</sub> .....	77.1	2.74	079	9.23
K <sub>2</sub> P <sub>1</sub> .....	76.6	2.44	073	8.55

*K <sub>0</sub> — 0 lbs. K <sub>2</sub> O per Acre	*K <sub>0</sub> = 0 lbs. P <sub>2</sub> O <sub>5</sub>
K <sub>1</sub> — 75 lbs.	"
K <sub>2</sub> = 150 lbs.	"
	P <sub>1</sub> = 100 lbs. P <sub>2</sub> O <sub>5</sub>

data were obtained for the ratoon crops harvested in 1947. In Table 11 are shown the yields in TSA for the Hawi I test. In this test, under conditions of severe drought and severe deficiencies of potash, the responses were definitely related to potash fertilization. It was rather curious that the phosphate fertilizer not only tended to depress the K-Index but also the apparent yield. Although the depressive effect on yield was not significant, it was more than just a trend. Also the P-Index levels were below the tentative normal 0.080 and yet no response to phosphate fertilization was observed.

The experiment in Halawa 5 gave the results as shown in Table 12.

TABLE 12. HALAWA 5—FIELD EXPERIMENT

	Sheath Moisture	P-Index	K-Index	TCA
K <sub>0</sub> *P <sub>0</sub> .....	75.0	076	1.93	65.0
K <sub>0</sub> P <sub>1</sub> .....	74.9	084	1.63	56.8
K <sub>1</sub> P <sub>0</sub> .....	75.5	076	2.48	74.8
K <sub>1</sub> P <sub>1</sub> .....	75.5	079	2.51	71.5
K <sub>2</sub> P <sub>0</sub> .....	76.0	073	2.77	79.8
K <sub>2</sub> P <sub>1</sub> .....	75.7	076	2.78	72.0

\* Treatments were the same as in Table 11.

Here again significant responses in yield are observed for potash fertilization, but phosphate fertilization seems actually to have depressed growth again, despite the fact that the P-Index is below .080. But here again we see from the sheath moisture levels that the plants were not adequately provided with moisture.

Thus, it appears at the outset that the P-Index was markedly affected by condition of drought and hence readings from one collection to the next might well mean little or nothing so far as actual phosphorus nutrition is concerned. Hence, the studies already referred to were undertaken to standardize the P-Index using data from Kohala as well as from Waialua where similar tests were being conducted. In Table 13 the average P-Index readings as well as the Standard P-Index readings are shown for the plant and ratoon crops of three Kohala field experiments.

TABLE 13. OBSERVED P-INDEX VS. STANDARD P-INDEX

	1944 P-Index		1946 P-Index	
	Observed	Standard	Observed	Standard
Hawi I.....	.086	.094	.076	.087
Halawa V.....	.086	.091	.077	.089
Union V.....	.098	.095	.097	.098
Mean.....	.090	.093	.083	.091

These data show that by eliminating the influences of sheath moisture and the total sugar variation, the Standard P Indexes for successive crops are stabilized. Also, by eliminating the effect of drought on these levels, all the Standard P-Index readings are above the .080 level and therefore we would not expect a response to phosphate fertilization. The reason for the depression of growth is not known at the moment, but two points develop—one is not to apply phosphate unless needed and the other is to apply it under the seed prior to applications of potash.

Essentially the same results obtained from a series of five similar experiments at Waialua where the Standard P-Index readings were above .080.

Recent experiments continue to confirm these results. Thus, a 1952 crop experiment involving phosphorus and potassium at Lihue in Field 7M showed no response to phosphate fertilization, but the check plot during the boom stage showed an SPI of .094, .094, .119, .101. Another Lihue experiment in the 1951 Crop in Field 5 Hm showed no response to phosphate but again all the critical SPI readings were above the .080 level. A phosphate test in 1 Am 1951 crop gave a response with the SPI at 076, 083, 068, 087, 081. One in 14M showed a response to phosphate with the SPI of the check plot being 066, 069, 070, 077, 080.

Three experiments at Pepeekeo show the SPI of .080 to be adequate for their fields. In Field 9, no response to phosphate was obtained in the plant crop with the SPI of the check plot being .087, .083, .084, .101. In field 69, fertilization with phosphate gave no response, but here again the SPI levels were .080, .084, and .080. In field 86A, an experiment gave a strong response to phosphate in the plant crop. Here, three forms of phosphate were used (ammophos, super and raw rock) in two amounts in the plant crop, 200 and 400 pounds  $P_2O_5$  per acre. The yields in TSA and the SPI for the crop are shown in Table 14.

In view of the actual SPI levels, the results are as might be expected. Paauhau also reports phosphate experiments which show gains with the SPI well below the .080 level.

TABLE 14. SPI READINGS AND YIELDS FOR THE PEPEEKEO FIELD 86A

	RR1	RR2	X	S1	S2	A1	A2	Age
10/22.....	.063	.073	.058	.068	.074	.062	.079	6.7
11/24.....	.064	.072	.070	.065	.075	.067	.075	7.8
5/17.....	.093	.089	.071	.080	.075	.083	.075	13.5
6/23.....	.082	.082	.082	.088	.087	.089	.086	14.7
7/28.....	.097	.095	.082	.092	.091	.094	.093	15.8
Yield-TSA.	9.6	11.4	9.3	10.6	11.6	10.4	11.2	

Thus, evidence from field experiments also supports the level .080. However, there is an area in which an inconsistency has occurred. At Olaa, five phosphate field experiments are being conducted all of which show responses. In three of them, the P-Index levels are well below the normal set up, but two of them gave responses even though the SPI levels were just at or just above the critical levels set up. Mr. Young tells me that up until they began using the colorimeter in the phosphorus analyses, they had trouble getting good checks in their determinations. While this may explain the inconsistency of the first experiment, it probably does not the second. At any rate, I hope the plantation continues to send me its data since in this way we can get at the nature of the inconsistency.

### PHOSPHATE FERTILIZER RECOMMENDATIONS

In general, whenever responses to phosphate fertilization occur, they are greatest in plant crops. It is seldom that a ratoon crop following a fertilized plant crop shows a response to additional fertilization. Also, it is not uncommon for the plant cane to show a marked early response to phosphate fertilization only to have the difference in growth disappear by harvest time. Yet, from the view point of the over-all plantation welfare it is advantageous to fertilize in areas where such temporary responses do occur. The fertilization program recommended below includes such situations.

#### Fertilization of the Plant Crop

If previous ratoons which received no phosphate were generally above an SPI level of .085 during the boom stage of growth (6-15 months of age and during May through October) no phosphate is recommended.

If previous ratoon crops were in the .075 to .085 range of the SPI, two hundred pounds of  $P_2O_5$  under the seed are recommended.

If previous ratoon crops show an SPI below .075, 400 pounds of  $P_2O_5$  under the seed are recommended and also additional dressings of  $P_2O_5$  prior to plowing to the knolls are recommended.

If previous ratoons required phosphate fertilization to maintain levels of the SPI, the following plant crop should be given the heavy fertilization.

#### Fertilization for Ratoon Crop

If the SPI of the plant crop or previous ratoon was at .075 or above, no phosphate application is needed for the subsequent ratoon. If the SPI is below .075, an application of 200 pounds  $P_2O_5$  is recommended. If the soils have high fixation characteristics, it is better to place the phosphate under the soil surface and near stools.

## FORMS OF PHOSPHATE

In general on near neutral and alkaline soils, soluble phosphate fertilizers should be used. Raw rock phosphate here is not desirable. Where the pH of the soil is in the lower acid range (pH 5.5-6.5) ammophos can still be used, although it is probably better to use some form of superphosphate.

If the pH is more acid than pH 5.5, it is better to use a mixture of super and raw rock—the superphos provides immediate availability while the raw rock because of its insolubility becomes available over a longer period.

## SUMMARY

To summarize, I have attempted in this short paper to give you a survey of the kind of data which were gathered through the years and the use made of them. First, straightforward analyses of the plant and its various parts are carried out in large members. Next, in order to simplify field work, a search for an index tissue is made which will give good guidance to the adequacy of the nutrient in the important plant functions of growth, photosynthesis, transpiration, storage, etc. Third, variations occurring in the Index because of uncontrollable environmental factors are eliminated. Fourth, a search is undertaken for the nutrient level which may be regarded as normal to guide management in intelligent and economic fertilization practices.

# THE PHOSPHORUS NUTRITION OF SUGAR CANE

CONSTANCE E. HARTT\*

The Department of Physiology and Biochemistry has emphasized three aspects of phosphorus nutrition of sugar cane: absorption by all parts of the plant, percentage composition of leaves and stems, and the utilization of phosphorus in the life of the plant, particularly in the formation of sugar. This paper reports our studies of absorption and distribution within the plant, including those with radioactive phosphate.

## THE ABSORPTION AND DISTRIBUTION OF RADIOACTIVE PHOSPHORUS

The work with radioactive phosphorus ( $P^{32}$ ) was started by placing 1 milli-curie of a solution of phosphate into the nutrient solution of a good-sized potted plant of cane variety 37-1933, illustrated diagrammatically in Figure 1. The pot was shielded with lead and a portable Geiger counter cell was mounted in such a way that readings could be made on the stalk above the second visible node. A positive net count was obtained in half an hour. A rapid survey of other parts of the plant indicated a net count of 110 at the spindle. The counts increased rapidly at all positions, and 18 hours later, counts up to 20,000 were observed in the leaves.

After 67 days, the plant was harvested, the several organs of the plant were separated, and the per cent of total counts was determined. Phosphorus was well distributed throughout the plant: 42 per cent in the stems, 20 per cent in the blades, 16 per cent in the suckers, and 8 per cent in the roots.

Figure 2 presents the results of a test in which a single root on one side of the plant was fed radioactive phosphorus. The new roots and the stem on the side of the plant which received radioactive phosphorus became more radioactive than the opposite side. But with the leaf, the opposite side was more radioactive.

A study of absorption of phosphorus by ratoons followed. More than 100 stools were used in studies of placement of fertilizer and it was found that placement of phosphate directly under old stools gave the best response.

Absorption of phosphorus by plant cane was also studied. Radioactive phosphate placed with the seed was used immediately (2). When applied in the irrigation water, the phosphorus was not taken up, but was strongly fixed. When applied at different distances from the cane line, phosphorus was absorbed if the roots were there. To be absorbed, phosphorus must be placed where the roots are.

\* Associate Physiologist, Department of Physiology and Biochemistry, Experiment Station, HSPA. Experimental work reported in this paper was done by the following members of the department: G. O. Burr, Constance E. Hartt, Ada Forbes, Tyrus Tanimoto, and Grace Sadaoka. The statistical analyses were the work of Ralph J. Borden and R. K. Tanaka of the Department of Experimental Statistics.

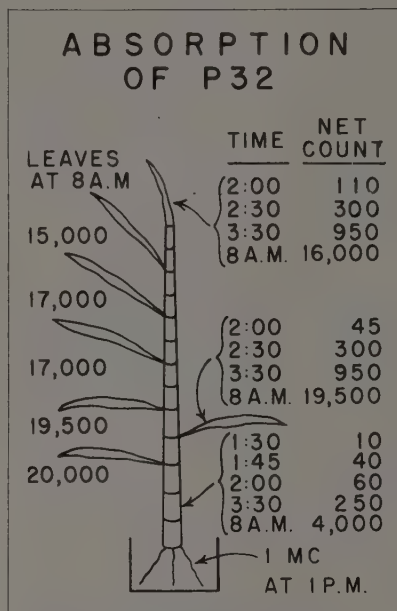


Figure 1. Absorption and distribution of radioactive phosphate by Variety 37-1933. Net counts obtained with portable counter.

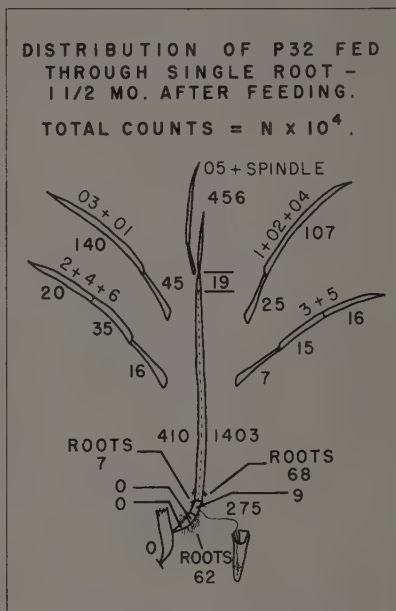


Figure 2. Single-root feeding of radioactive phosphate. (Illustration by T. Tanimoto)

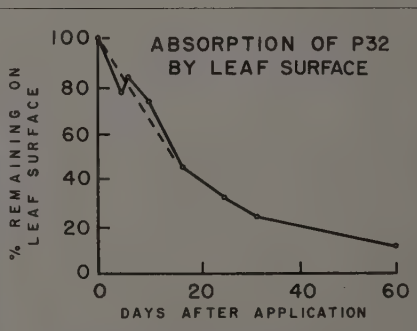
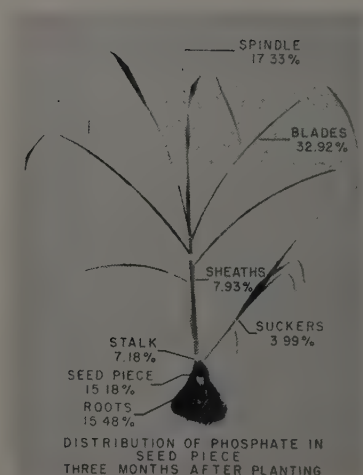
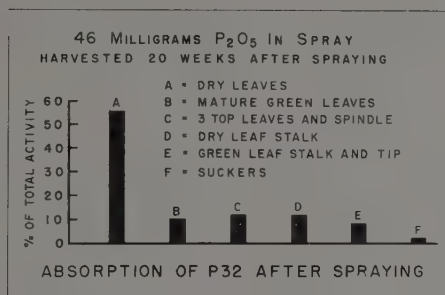


Figure 4. Absorption of radioactive phosphate pointed on leaf surface. (After T. Tanimoto (2))

Figure 3. Radioactive phosphate absorbed from a seed piece was well distributed in the plant three months later. (Illustration by T. Tanimoto)

Figure 5. Absorption of radioactive phosphate sprayed on caged potted plants. Cooperative experiment by Departments of Agronomy and of Physiology and Biochemistry.



Studies (3) with radioactive phosphorus have shown that as much as 85 per cent of the phosphorus in a seed piece may be taken into the new plant as presented in Table 1. As much phosphorus was absorbed from a two-eye cutting by the plant germinating from either eye alone as by the plant germinating from both eyes together. When adjacent eyes germinated, the two plants competed for stored phosphate and neither was as rich in phosphate as a single plant.  $P_{32}$  absorbed from a seed piece was well distributed in the plant three months later, as shown in Figure 3.

TABLE 1. ABSORPTION OF RADIOACTIVE PHOSPHATE FROM SEED PIECES

Seedpieces are Numbered from Base to Top of Cane Plant and Growing Eyes are Identified as Either Upper or Lower

	#1		#3		#5	
	Lower	Upper	Lower	Upper	Upper	Lower
Dry weight of plants . . . . .	88.5 g.	93.5 g.	57.5 g.	63.0 g.	95.5 g.	94.5 g.
Per cent of $P_{32}$ absorbed by plant.	82.8	81.4	36.9	48.5	85.1	84.6
	85.4					

Phosphorus can also be absorbed directly by the leaf (2). Figure 4 shows the rate of absorption of  $P_{32}$  which had been painted on a blade. About 25 per cent was absorbed in the first 10 days and most of it was absorbed in 60 days. Radioactive phosphate fed to the blade was stored mainly in the stem. New leaves and growing tip became very rich. The lower surface of the leaf was found to be more efficient in absorbing  $P_{32}$  than the upper surface.

The sheath was also found able to take in phosphorus directly (2). When  $P_{32}$  was applied to the dewlap with a pipette, the radioactive phosphorus entered the sheath and moved into the spindle and new leaves.

Foliar application of radioactive phosphate by air was studied, using  $P_{32}$  in potassium dihydrogen phosphate. Radioactive counts were made 20 weeks later. 45 per cent of the applied phosphate was distributed throughout the plant, especially in the new leaves and dry stalk (B, C, and D in Figure 5) indicating very good utilization of sprayed phosphate (3).

To recapitulate, these studies with radioactive phosphorus illustrate the rapidity with which phosphate is absorbed by the roots and distributed throughout the plant. They also point to foliar application as a means of overcoming phosphate deficiency in growing plants.

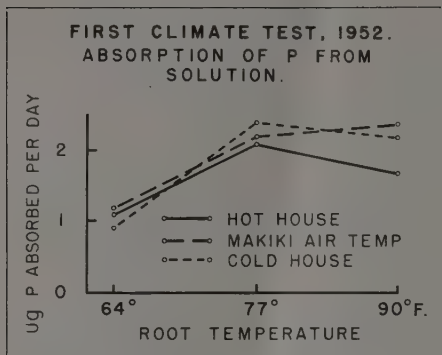


Figure 7. Effects of air and root temperatures upon total dry weight at final harvest—age four months.

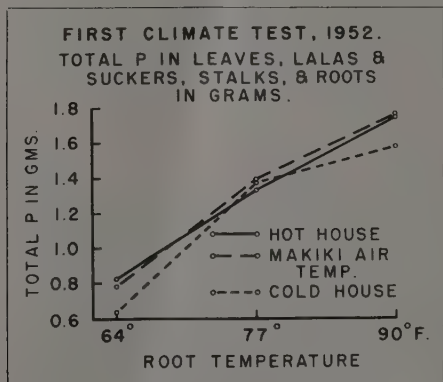


Figure 9. Since low root temperature decreased absorption of phosphorus and growth of plant to the same extent, the percentage of phosphorus in the plant remained nearly uniform.

Figure 6. Effects of air and root temperatures upon absorption of phosphorus from nutrient solutions.

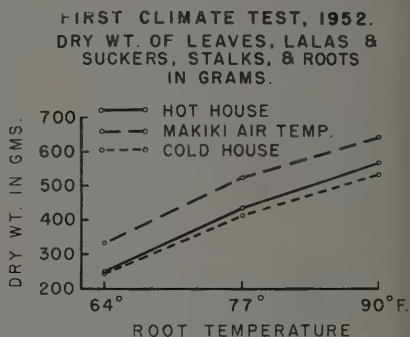
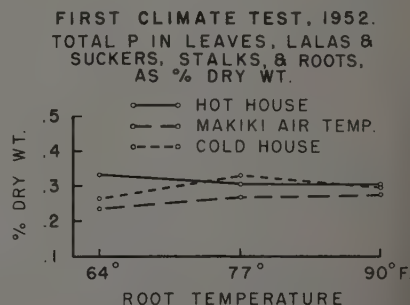


Figure 8. Effects of air and root temperatures upon total grams of phosphorus in the plants.



## ANALYTICAL STUDIES OF ABSORPTION AND DISTRIBUTION OF PHOSPHORUS

A study of absorption of phosphorus from nutrient solutions is in progress, the Climate Project, in which sugar cane plants are grown at controlled air and root temperatures. In the first climate test, 1952, three air temperatures were maintained: one atmospheric temperature (Makiki), and the others respectively 9° higher and 9° lower. Phosphorus was analyzed in samples of the new nutrient solution, shortly after changing, and again after the period of absorption, each time after the water level was brought up to mark. The difference is plotted as absorption in Figure 6. It should be emphasized that the plants in the climate tests all received adequate supplies of phosphorus. Absorption of phosphorus at all three air temperatures was least at 64° root temperature. As shown by total dry weight at final harvest, at age of four months, growth was least at 64° root temperature and maximum at 90° (Figure 7). Total phosphorus in the entire plant was also least at 64° root temperature and maximum at 90° (Figure 8). But the percentage of phosphorus in the plant as a whole remained remarkably constant (Figure 9). The low root temperature decreased absorption of phosphorus and growth of the plant to the same extent, resulting in a nearly uniform percentage of phosphorus in the plant. The second climate test gave similar results.

A third climate test is now in progress, in which the air temperatures are Makiki, Cold or 9° F. less than Makiki, and Very Cold or 18° F. less than Makiki. The root temperatures are 56°, 60°, 66° and 74° F. Three determinations have been made of the amount of phosphorus absorbed in seven days, and the averages of these three determinations are presented in Figure 10 (4). At Makiki and cold air temperatures, the absorption of phosphorus was positively correlated with root temperature. Absorption at 74° root temperature varied directly with air temperature. But absorption at 60° root temperature varied inversely with air temperature. These plants will be analyzed for phosphorus at the final harvest.

Another experiment was conducted in which plants at Makiki air and root temperature were supplied with different amounts of phosphorus: basic, low and very low. Determinations of the absorption of phosphorus have been made several times with similar results. The results of a typical test are graphed in Figure 11. The basic solution still contained phosphorus after 26 days, whereas the very low phosphorus solution was depleted of phosphorus after the first week. Although the basic solution contained twice as much phosphorus as the low phosphorus solution, and four times as much as the very low phosphorus solution, the initial absorption rates of the three sets of plants were the same. When the very low phosphorus solution was changed every week, the plants took up as much phosphorus as the basic plants. Only when the very low phosphorus solution was depleted of phosphorus were symptoms of phosphorus deficiency obtained. The plants grown in the basic solution received a continuous supply of phosphorus and became larger than the plants grown in the low and very low phosphorus solutions.

Figure 12 relates the absorption of phosphorus to phosphorus composition of the plant. The results of eight studies of absorption of phosphorus, recalculated as percentage of absorption from the basic solution, were averaged and are presented in the block diagram. Also, at monthly intervals, blade punch samples were taken, analyzed for total and inorganic phosphorus, and calculated as per cent of

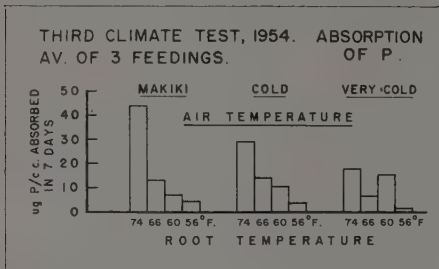


Figure 10. Temperature effects on absorption of phosphate when supply is adequate. (4)

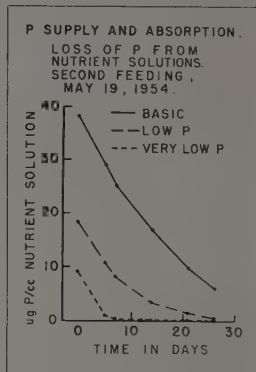


Figure 11. Plants of the same size absorbed phosphorus from nutrient solutions at the same initial rate regardless of the amount of phosphorus in the nutrient solution.

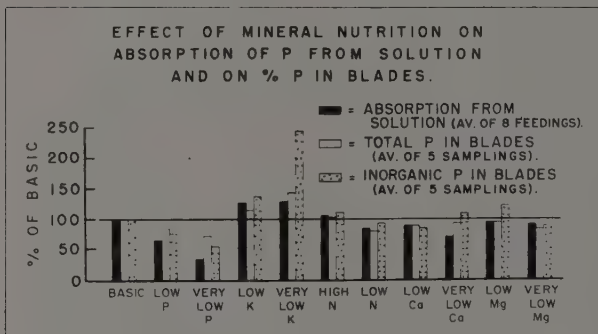


Figure 12. Relation of absorption of phosphorus to phosphorus composition of the plant.

basic. The line at 100 per cent is the basic level. Confining our attention for the moment to the basic, low P, and very low P, note that the inorganic phosphorus in the blades bears a closer relation to phosphorus absorbed than does the total phosphorus. This is because the organic phosphorus (not depicted here) is slow to respond. Inorganic phosphorus in the very low phosphorus blades was 56 per cent of basic, whereas organic phosphorus was 85 per cent of basic.

A similar study with potassium, nitrogen, calcium, and magnesium has revealed that plants with low supplies of potassium absorbed more phosphorus than the basic controls, and as a result their leaves contained more phosphorus, especially inorganic phosphorus. Deficiencies of nitrogen, calcium, and magnesium had no striking effect on absorption of phosphorus in this experiment.

Summing up the results of these studies of absorption of phosphorus, we have found:

(1) That low root temperatures affect absorption of phosphorus and growth of the plant to about the same extent, resulting in nearly uniform percentages of phosphorus in the plant.

(2) Plants of the same size absorbed phosphorus from nutrient solutions at the same initial rates, regardless of the amount of phosphorus in the nutrient solution.

(3) Cutting the phosphorus in the nutrient solution to 25 per cent of basic and allowing it to run out between renewals, decreased the absorption rate of

phosphorus to 35 per cent of basic. Inorganic phosphorus in blade #7 of these plants was 56 per cent of basic, while organic phosphorus was 85 per cent of basic.

(4) Potassium deficiency in the nutrient solution caused an increase in absorption of phosphorus by the blades. This was particularly apparent with respect to inorganic phosphorus.

Now let us consider the distribution of phosphorus in the plant. Chemical analyses were made on leaves from plants supplied with high, basic, and low amounts of phosphorus, the high being twice the basic, and the low, half the basic. The results are presented in Table 2. The 95 per cent alcohol extract and the residue after water contained only organic phosphorus. The acid 60 per cent alcohol extract contained most of the inorganic phosphorus and some organic phosphorus also. The sum of the total phosphorus in the extracts plus the phosphorus in the residue agrees well with total phosphorus as measured by analyses of leaf punches.

A study was made of the forms of phosphorus in the plant, looking for one which was four times as high in the high P series as in the low P series, since that was the ratio in the nutrient solution. Punches from two blades of the low P series and two of the high P series were analyzed for total and inorganic phosphorus and the results are recorded in Table 3. The average for inorganic phosphorus in the high P series was 3.9 times the average in the low P series. Several forms of organic phosphorus were also determined, but the result for inorganic phosphorus was the closest we came to a 4:1 ratio. In the low P blades, inorganic phosphorus

TABLE 2. PHOSPHORUS COMPOSITION OF SUCCESSIVE EXTRACTS OF LEAVES COMPARED WITH PUNCHES FROM THE SAME LEAVES

High, Basic, and Low P P in Primary Blade #4 as Per Cent Dry Weight August 31, 1953		Var.: 1933 Age: 14 Months		
Fraction	Series	Total P	Inorganic P	Organic P
6 punches.....	Low P	.118		
	Basic P	.142		
	High P	.234		
95% alcohol extract.....	Low P	.019	0	.019
	Basic P	.020	0	.020
	High P	.023	0	.023
Acid 60% alcohol (neutral) ..	Low P	.030	.021	.009
	Basic P	.033	.027	.006
	High P	.083	.068	.015
60% Alcohol Wash.....	Low P	.017	.010	.007
	Basic P	.019	.012	.007
	High P	.046	.035	.011
Water Extract.....	Low P	.001	.001	.000
	Basic P	.001	.001	.000
	High P	.004	.002	.002
Residue after water.....	Low P	.041	0	.041
	Basic P	.043	0	.043
	High P	.046	0	.046
Sum of extracts + residue...	Low P	.108	.032	.076
	Basic P	.119	.040	.076
	High P	.202	.105	.097

TABLE 3. LEAVES OF PLANTS SUPPLIED WITH PHOSPHORUS IN A 4:1 RATIO CONTAINED INORGANIC PHOSPHORUS IN A 3.9:1 RATIO

High and Low P		Var.: 1933	
P in Secondary Blades #4 and #5 as Micrograms P/Square Centimeter			
September 9, 1953			
Series	Total P	Inorganic P	Organic P
Low P #4.....	11.9	3.6	8.3
Low P #5.....	9.7	3.2	6.6
High P #4.....	23.6	11.4	12.2
High P #5.....	27.3	15.4	11.9
Av. Low P.....	10.8	3.4	7.4
Av. high P.....	25.4	13.4	12.0
Ratio high/low.....	2.3	3.9	1.6
% of total P:			
Low P.....		30.5	69.5
High P.....		52.7	47.3

was 30 per cent of total phosphorus, but in the high P blades, inorganic phosphorus was 53 per cent of total phosphorus, indicating that in luxury feeding of phosphorus it is the inorganic form which accumulates.

All of the blades were then analyzed separately and Table 4 shows that all the blades of the low P series contained less total phosphorus than the high P series, and that the difference was much more conspicuous in the inorganic than in the organic phosphorus. Blade #4, having the lowest figure in the column for inorganic phosphorus as per cent of total phosphorus, was selected as the indicator blade.

Four cane varieties growing at Makiki in soil adequate in phosphorus were analyzed for phosphorus, with the results in Table 5. The inorganic phosphorus in the blades was always more than 40 per cent of the total phosphorus.

TABLE 4. INORGANIC PHOSPHORUS VARIES MORE THAN ORGANIC PHOSPHORUS IN BLADES OF PLANTS WITH HIGH AND LOW PHOSPHORUS SUPPLY

High and Low P			Var.: 1933		
P in Secondary Blades 1-8 as Per Cent Dry Weight					
September 29, 1953					
Series	Total P % Dry Wt.	Inorganic P		Organic P	
		% Dry Wt.	% of Tot. P	% Dry Wt.	% of Tot. P
Low—1.....	.234	.094	40	.140	60
2.....	.216	.085	39	.131	61
3.....	.177	.065	37	.112	63
4.....	.200	.063	31	.137	69
5.....	.162	.055	34	.107	66
6.....	.166	.064	38	.102	62
7.....	.197	.099	50	.098	50
8.....	.197	.100	51	.097	49
High—1.....	.391	.219	56	.172	44
2.....	.451	.276	61	.175	39
3.....	.397	.232	58	.165	42
4.....	.425	.260	61	.165	39
5.....	.407	.272	67	.135	33
6.....	.392	.224	57	.168	43
7.....	.600	.407	68	.193	32
8.....	.641	.430	67	.211	33

TABLE 5. COMPARING PHOSPHORUS IN BLADE NO. 4 OF FOUR VARIETIES GROWING IN A MAKIKI FIELD ADEQUATELY SUPPLIED WITH PHOSPHORUS

5 months old					
Variety	Total P Ug/ cm <sup>2</sup>	Inorganic P		Organic P	
		Ug/ cm <sup>2</sup>	% of Tot. P	Ug/ cm <sup>2</sup>	% of Tot. P
1933.....	18.8	8.6	45.7	10.2	54.3
3098.....	16.7	9.2	55.1	7.5	44.9
2915.....	17.0	8.2	48.2	8.8	51.8
7028.....	14.8	6.4	43.2	8.4	56.8

Four parts of the same plant were analyzed and the results tabulated in Table 6. Most of the phosphorus in the blade was organic. Most of the phosphorus in the sheath, internodes 8-10, and basal internode was inorganic. The total phosphorus in the internodes 8-10, in plants grown in Makiki soil, was nearly two-tenths of one per cent.

TABLE 6. PHOSPHORUS IN VARIETY 1933 IN MAKIKI SOIL, ADEQUATE P

Part	Age: 8 Mos.	January 19, 1954			
	Total P % Dry Wt.	Inorganic P		Organic P	
		% Dry Wt.	% of Tot. P	% Dry Wt.	% of Tot. P
Blade #4.....	.244	.084	34.4	.160	65.6
Sheath #4.....	.297	.224	75.4	.073	24.6
Internode 8-10....	.198	.157	79.3	.041	20.7
Basal internode....	.146	.101	69.2	.045	30.8

## ANALYTICAL STUDIES OF FIELD EXPERIMENTS

An attempt was then made to find out which part of the plant is the most responsive to phosphate fertilization in the field, which form of phosphorus would be the best for routine analysis, and what the critical level is for that form of phosphorus in that part of the plant. Several replicated field experiments on the island of Hawaii were studied and analytical results were submitted for statistical analysis.\*

In Pepekeo Experiment 82AxFP, there were 10 plots with no phosphate, and five plots of each form of phosphate which received 200 pounds residual plus 200 pounds current phosphate, and five plots with 400 pounds residual and no current phosphate. The forms of phosphate were raw rock, superphosphate, and ammophosphate. Soil phosphorus was approximately 10 parts per million. Single stalks were taken from each plot, and four parts analyzed for total and inorganic phosphorus. Table 7 records the coefficient of variation and the per cent gain for 400 pounds P<sub>2</sub>O<sub>5</sub> compared with 0 pounds P<sub>2</sub>O<sub>5</sub>. Although the blades had the lowest coefficient of variation, they also had the lowest per cent gain. The two portions of the stem had considerably higher per cent gain than coefficient of variation for both total phosphorus and inorganic phosphorus.

\* The assistance of O. H. Lyman and K. Lyman Bond, Hawaii Island Representative and Asst. Island Representative, respectively, is gratefully acknowledged.

TABLE 7. STATISTICAL STUDY COMPARING FOUR PARTS OF THE PLANT

Pepeekeo Exp. 82 A $\times$ FP		Var.: 3098	Age: 7.6 Mos.	
Part	Total P CV    % Gain		Inorganic P CV    % Gain	
Blades.....	8.1    9.7		20.0   17.5	
Sheaths.....	25.0   28.8		26.0   29.3	
8-10.....	35.5   54.5		45.5   85.7	
Basal.....	22.2   38.1		25.0   62.5	

The same experiment was sampled again, taking five check plots and 5 SI, or superphosphate, plots. Leaves were omitted this time, and five stalks per plot were analyzed separately. Table 8 shows that the per cent gains in phosphorus in both parts of the stem and for both forms of phosphate were again considerably higher than the corresponding coefficients of variation.

TABLE 8. STATISTICAL STUDY OF STALK PHOSPHORUS

Pepeekeo Exp. 82 A $\times$ FP		Var.: 3098	Age: 9 Mos.	
Part	Total P CV    % Gain		Inorganic P CV    % Gain	
8-10.....	37.8   70.3		46.1   114.3	
Basal.....	26.0   72.7		35.8   112.5	

Olaa Experiment 101 (a) APCa  $\times$  ANK was studied, taking five check plots (without P) and five A plots (with 200 pounds  $P_2O_5$  as ammophosphate). Soil phosphorus was 27 parts per million, but thin and rocky. Five stalks per plot were analyzed separately for total and inorganic phosphorus in four parts of the plant. The results were statistically analyzed. Table 9 records the coefficients of variation and per cent gain. The results at Olaa confirmed the findings at Pepeekeo in showing a much bigger response in stems than in leaves.

These three statistical studies showed that either the 8-10 or basal internodes would form a reliable indicator tissue for phosphorus. The 8-10 internode tissue was selected because it is easier to get in the field. Either total or inorganic phosphorus could be used to determine response to phosphate fertilization; but total phosphorus regularly had a lower coefficient of variation than inorganic phosphorus, and the analysis for total phosphorus in plant tissue is in some ways easier than for inorganic phosphorus. For these reasons, total phosphorus in internodes 8-10 was selected as the indicator for phosphorus level in the plant.

Another important question to answer is, how many stalks are needed for a reliable result? The statistical study of the Olaa experiment indicated that for a

TABLE 9. STATISTICAL STUDIES SHOWING A MUCH BIGGER RESPONSE IN STEMS THAN IN LEAVES

Olaa Exp. 101 (a) APCa $\times$ ANK		Var.: 3098	Age: 6 Mos.	
Part	Total P CV    % Gain		Inorganic P CV    % Gain	
Blades.....	10.2    7.2		21.8    14.7	
Sheaths.....	21.5   12.8		24.1   13.5	
8-10.....	30.0   82.7		40.5   100.0	
Basal.....	23.0   54.8		31.6    78.6	

TABLE 10. PHOSPHORUS ANALYSES OF FIRST RATOONS IN WHICH THE PLANT CROP HAD A SIGNIFICANT GAIN IN TONS SUGAR PER ACRE FOR 200 LBS.  $P_2O_5$

Olaa Exp. 101 (a & b) APCa × ANK				Var.: 44-3098	
Soil P: 27 p.p.m.				Age: 9-10 Mos.	
Internodes 8-10					
Plot	Treatment				
No. = 8	#P <sub>2</sub> O <sub>5</sub>	#CaO	% Total P	% Gain	
X.....	0	0	.031		
A.....	200	0	.046	48.4	
B.....	200	290	.051	64.5	
C.....	200	580	.042	35.5	
A+					
B+.....	200		.046	48.4	
C					
			LSD .009	C.V. 14.3%	

survey with no replicates, nine stalks from one plot would measure a 30 per cent difference. For an experiment with replicates, five stalks per plot in a composite sample should give a reliable answer.

Limiting the study to total phosphorus in the internodes 8-10 only, the same Olaa experiment was sampled again with the results given in Table 10. The correct figure for soil phosphorus for this crop is 27 parts per million. Significant differences in phosphorus were obtained in all treatments, and the per cent gains were all greater than the coefficient of variation. The check plots averaged 0.031 per cent total phosphorus in internodes 8-10. These plants were ratoons and the yields at harvest are not yet known. The plant cane had shown a significant gain in tons sugar per acre.

The results of a similar study of Olaa Experiment 103 AFP (Res) are presented in Table 11. An especially high response was given by series 2, which received 400 pounds residual plus 200 pounds current  $P_2O_5$ . The plant crop of this test also had a significant gain in sugar. The check plots had 0.022 per cent total phosphorus in this Olaa experiment, which may be compared with nearly two-tenths of one per cent at Makiki (Table 6).

TABLE 11. PHOSPHORUS ANALYSES OF FIRST RATOONS IN WHICH THE PLANT CROP HAD A SIGNIFICANT GAIN IN TONS SUGAR PER ACRE FOLLOWING APPLICATION OF PHOSPHATE

Olaa Exp. 103 AFP (Res.) Soil P: 20-30 p.p.m. Internodes 8-10				Var.: 44-3098 Age: 8 Mos.	
Plot	No.	#P <sub>2</sub> O <sub>5</sub> Res. Current		% Total P	% Gain
X.....	8	0	0	.022	
1.....	12	400	0	.029	31.8
2.....	12	400	200	.040	81.8
				LSD .005	C.V. 15.6%

In Hakalau Experiment 118 AP  $\times$  Ca, Table 12 shows that the plants with 0 phosphate had 0.050 per cent total phosphorus, and gave a significant gain in percentage of phosphorus for the application of 200 pounds  $P_2O_5$ . A small but insignificant gain in tons sugar per acre was obtained in the plant crop.

In Hakalau Experiment 119 (a) A  $\times$  FP (Res), the plants which received no phosphate had 0.045 per cent total phosphorus in the internodes 8-10 as recorded

**TABLE 12. PHOSPHORUS ANALYSES OF FIRST RATOONS IN WHICH THE PLANT CROP GAINS IN TONS SUGAR PER ACRE WERE NOT SIGNIFICANT**

Hakalau Exp. 118 AP × Ca Soil P: 19 p.p.m.				Var.: 44-3098 Age: 1 Year	
Internodes 8-10					
Plot	No.	Treatment		% Total P	% Gain
		#P <sub>2</sub> O <sub>5</sub>	#CaO		
A.....	18	0		.050	
B.....	18	200		.070	40.0
				LSD .006	C.V. 15.0%
C.....	12		0	.055	
E.....	12		290	.059	7.3
D.....	12		580	.065	18.2
				LSD .007	C.V. 15.0%

in Table 13. A significant gain in percentage of phosphorus was obtained only in the series which received current phosphate application of 200 pounds. In the plant crop, the gains in tons sugar per acre were not significant.

**TABLE 13. PHOSPHORUS ANALYSES OF FIRST RATOONS IN WHICH THE PLANT CROP GAINS IN TONS SUGAR PER ACRE WERE NOT SIGNIFICANT**

Hakalau Exp. 119 (a) A X FP (Res.) Soil P: 22 p.p.m.				Var.: 44-3098 Age: 1 Year	
Internodes 8-10					
Plot	No.	#P <sub>2</sub> O <sub>5</sub>		% Total P	% Gain
		Res.	Current		
X.....	4	0	0	.045	
1.....	6	200	200	.072	60.0
2.....	6	400	0	.059	31.1
		LSD <sup>4</sup> vs. <sup>6</sup>		.016	C.V. 18.0%
		6 vs. 6		.014	

A series of experiments at Kohala was studied, where the plant cane showed no differences in growth. These experiments were combined for statistical analysis and showed no significant differences in percentage of phosphorus, comparing 500 pounds P<sub>2</sub>O<sub>5</sub> with 0 pounds P<sub>2</sub>O<sub>5</sub>. The four parts of the experiment were on soils of different phosphorus contents. The check plots (with no phosphate) were compared as to total and inorganic phosphorus, with the data presented in Table 14. The lowest figure for total phosphorus was in the b experiment, with 0.037 per

**TABLE 14. PHOSPHORUS ANALYSES OF CHECK PLANTS IN EXPERIMENTS WITH FOUR LEVELS OF SOIL PHOSPHATE**

		Kohala Exp. 198 (b, c, d, a) × Plots P in Internodes 8-10		Age: About 1 Yr.	
Exp. & Var.	p.p.m. P in Soil	P as % Dry Weight			P as % of Total P Inorganic
		Total P	Inorganic P	Organic P	
(b) 2915.....	21	.037	.023	.013	62.1
(c) 2915.....	54	.065	.045	.020	68.6
(d) 2915.....	94	.125	.099	.027	77.9
(a) 3098.....	105	.110	.085	.025	77.4

cent. This figure may be compared with the plants at Pepeekeo which had received 400 pounds  $P_2O_5$  per acre and were growing well, where the internodes 8-10 averaged 0.034 per cent total phosphorus.

## SUMMARY

Summing up the studies of phosphorus distribution in field-grown plants, the best indicator tissue so far found is the stem. Either the internodes 8-10 or basal internodes give a reliable answer, but since the internodes 8-10 are easier to obtain in the field, they were used in these surveys. Inorganic phosphorus is the most responsive form, but since it has a higher coefficient of variation and the method is more difficult, total phosphorus is the determination selected for routine use. For a replicated experiment, composite samples of five stalks per plot should be taken for reliable results. Further studies are now under way.

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## DISCUSSION

**Philip Conrad:** In the Olaa experiment, I want one point cleared up. You said there were 27 ppm phosphorus in the soil and the check plot showed .031, I believe. You also got a response over the check plot, so that would mean with the Truog of 27 ppm, you still got a response to phosphate. Is that correct?

**Dr. C. E. Hartt:** That is correct. That field has been analyzed, Dr. Ayres tells me, for phosphorus a number of times, and I think the slide shows 46 ppm, but he corrected me on that the other day after the slide was made. Actually, this soil was 27 parts at the time this experiment was running. However, I could emphasize that the soil was thin and rocky. Dr. Ayres will handle the work about the phosphorus in the soil, probably, in his paper, but that is correct. The percentage of total phosphorus in the 8-10 internode was .031 and you can see that every treatment went up. And in the other Olaa experiment where it was .022, it also went up. At Pepeekeo, the result wasn't shown on the slide. It was .022 and went up to an average of .034.

**S. Tutton:** I have a question for Dr. Burr on a point raised by Dr. Clements. You say that some of the older sheaths might possibly give a better index for potassium than the younger ones. Would you also say that is true for phosphorus?

**G. O. Burr:** I made that suggestion simply on the basis of lack of slope. When you're selecting a sample, you have about a 10-day spread so that sometimes this sheath, which we call #5, just by chance will be just ready to be #6. You understand that, I'm certain, since a leaf emerges about every 10 days. So, if you're on a steep slope and it so happens you work a little farther down that slope because you chose the older leaves, then you'll get a variability which you wouldn't get if you were working on a portion of the tissue where the slope was relatively flat. That's what I had in mind there. I don't know anything about the statistical reliability of such a spot as indicated.

**H. F. Clements:** I'd like to add something to that. That's why we used four sheaths. That is, if you take just one sheath, then obviously you run into this plus or minus period, because between the time that a leaf actually pokes its tip out of the spindle and the time that the next one pokes, it may be as little as seven days. In the middle of summer, you may have as many as five sheaths in the course of a month, where in the winter you may have only two. But by having four sheaths, that was the point of that original selection. We standardize and get our level then so that it is completely uniform. More important, I think this is quite an important point—you see, our interval is 35 days; now during that 35 days, we would normally expect four leaves to be produced. Now then, the leaves that we sample are leaves that have been produced since the last sample and give us a true measure of that short period of 35 days of life. Now, I think it is true, Dr. Burr, isn't it, that at one time you did recommend the use of the old sheaths for the phosphorus index?

**G. O. Burr:** Well, if I did, I've completely forgotten it. In fact, I have never personally attempted to study the phosphorus index until this year. I may have made some remarks in talking off the record about things I didn't know much about, but we have never really settled down to try to study phosphorus until now.

**R. P. Humbert:** I'd like to ask Harry a question regarding his discussions of the Hawi experiments. We have recently completed an examination of the various amounts of N, P, and K tests over the past 15 years—that work will be presented later, too—but I do not recall a single instance where we got a significant decrease in yields from phosphate fertilization. I am wondering if your comments, Harry, shouldn't be interpreted in light of nutrient balance problems—you mentioned potash as one possibility.

**H. F. Clements:** Well, in this particular test, to have the record completely straight, I didn't say that it was a significant response. Statistically, it was not significant. Statistically, the depression of the phosphorus index, like potash and vice versa, that was significant—highly significant. In both tests, however, the loss of yield due to phosphorus was very real. That is, as I say in the paper, more than just a trend. Now, I think in pineapples, Dr. Sideris claims the invalidation of iron by phosphate applications, but I don't think that's the case in sugar. I'm inclined to think this: I'm inclined to think that there is not necessarily an antagonism in the sense of iron antagonism, but an antagonism between phosphate and potash being applied to plant fields together. Actually, in all of our practice now, we go toward phosphate under the seed, but we don't apply potash at all any more under the seed—that is, along the Hilo Coast on the Brewer plantations—because we just don't get responses there and we don't get this depression. But I do think, Roger, that if you look through the literature fairly thoroughly, you will find many, many cases where there has been a depression of growth by phosphate application. Now, there is another point that Dr. Hartt mentioned I would like to answer since we are talking about this fertilizer under the seed. The point mentioned that the phosphorus has to be under the seed to be absorbed. I'm not questioning your statement—undoubtedly that is true for those circumstances. But the thing is, where you have soils of comparatively low fixation, you can put your phosphate on any time you want to. As a matter of fact, at Ewa in Field 5, where the pH is up above six, at any rate, we had a continuous fertilizing experiment. Billy Livingston installed it, and it didn't take very long before Bob Cushnie, who is sitting back there, was beginning to squawk that the whole test looked lousy, and we both agreed that it did. Well, the first log samples that came in showed phosphate levels of .04, which is very, very low, actually. It happened to be a spot in a field. Well, Billy, recognizing that the test had already been pretty well lousy up so far as the continuous feeding was concerned, put on phosphate—ammophos—on two of the plots, and not on the rest, and the response was extremely striking. The two plots jumped from .04 up to over .1 and continued all the way through the crop. At Hutchinson, we had another circumstance which Earl Nielsen and Fred Schattauer pointed up to me on one of my trips there, where a particular field was dropping quite low on nitrogen as well as phosphate. Well, it doesn't take much of a genius to suggest ammophos at a time like that, and so I said, "Why don't we put ammophos on by air?" Now there, again, the soils are not especially acid, and the response was very good. That was put on at 12 months of age and they measured something over a ton of sugar gain. Roger, on your balance, I don't go very much for that—that is, the balance of the nutrients. I feel fairly convinced of this: that if we have the various nutrients adequately supplied, we can have trouble from excesses, but it has to be way the great extreme. I don't think that in the middle ground it matters very much. I must confess I can't see this balance idea, outside of those ranges, that is, so long as we have the nutrient levels adequately supplied for each one, I think our plants won't show much trouble.

**L. D. Bayer:** That's the subject of the next discussion.

# NUTRIENT BALANCE IN SUGAR CANE NUTRITION

R. P. HUMBERT\*

Nutrient balance has been the subject of research in medical fields for generations. Balanced diets have been partly responsible for the increased vigor in American youth. Almost half of the millions of men rejected in the draft of World War II were revealed to be malnourished.

Similar relationships hold in the plant world as in the animal world. The soils of the Ozarks of Missouri are weathered from granite and support a natural vegetation of scrub oaks six to 10 inches in diameter. Intrusions of basic igneous dikes are found scattered through the Ozarks region. The soils weathered from these basic dikes support a natural vegetation of magnificent white oaks, many over three feet in diameter. The striking contrast in natural vegetation within a distance of a few yards reflects the importance of a proper diet.

Where nutrient deficiencies exist, plants supported by these soils are generally dwarfed in size, lack vigor, and are more susceptible to damage by insects and diseases. Nutrient deficiencies are often caused by an over-abundance, or by toxic quantities, of one or more of the elements, such for example as magnesium, excessive amounts of which are found in many places all over the world. Magnesium is used as an example because some of our sugar-producing soils contain relatively high levels of exchangeable magnesium. In New Guinea and other tropical islands of the Pacific, the author has seen whole hillsides of soils weathered from serpentine and other ultra basic rocks high in magnesium, which are practically barren of vegetation. The excess of magnesium over and above the normal plant requirements resulted in restricted growth. The Connowingo soils of Maryland and Eastern Pennsylvania and the Nipe soils of Cuba are other examples of nonproductive soils weathered from ultra basic rocks, where abnormally high absorption of Mg, chromium, etc., results in poor plant growth.

Travel to New Guinea or to Cuba is not necessary to find examples of improper nutrient balance. Good examples are found in the Hawaiian sugar industry! The growth failure areas of Maui and the thousands of acres where leaf freckle is a problem represent specific challenges to the physiologists and agronomists.

## Liming

A review of the old liming experiments conducted on the Hilo and Hamakua Coasts of Hawaii has resulted in some very interesting deductions. In these tests, large quantities of lime, often ranging from 5 to 20 tons per acre, were used

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TABLE 1. FERTILITY LEVEL OF HILO COAST SOILS

Plantation	Fld. No.	Elev.	Soil Family	pH	Exchangeable cations				Ca/Mg Ratios	Exchange Capacity me/100	Base Saturation %	Available P ppm	Organic Matter %
					Ca ppm	Mg ppm	K ppm	Total me/100 gms.					
Hilo Sugar.	26	750	K-6	5.5	376	88	86	2.82	2.60	40.1	7.0	33	14.3
	12	1250	K-6	5.2	162	102	74	1.84	.96	35.5	5.2	25	13.9
	25	1500	K-8	5.0	146	46	86	1.33	1.91	44.5	3.0	23	10.7
	95	500	K-6	5.2	316	100	86	2.62	1.93	34.8	7.5	28	13.8
Onomes.	71	750	K-6	5.3	122	174	186	2.00	1.40	45.9	6.1	21	15.7
	21	1000	K-6	5.0	42	46	219	1.15	.55	44.9	2.6	24	16.7
Pepeekeo.	10	500	K-6	5.3	650	121	106	4.51	3.28	38.4	11.7	31	14.4
	23	750	K-6	5.2	336	88	109	2.68	2.33	33.8	7.9	32	15.1
	79	1250	K-8	5.0	62	27	74	.72	1.38	45.8	1.6	28	15.8
	9-1	250	A-5	5.1	476	55	74	3.02	5.33	43.7	6.9	34	13.7
Hakalau.	13C-4	1250	K-6	5.0	115	21	86	.56	.36	39.3	9	22	18.6
	136-C3	1250	K-6	4.6	20	20	78	.46	.32	49.1	.9	26	17.0

as soil amendments. Yield increases as a result of the treatment were rare, and in many instances decreases in yields of cane and sugar resulted. Why, in these highly-leached, acid soils did liming fail to give gains?

The answer is found in the soil! Unpublished data of Ayres (Table 1) show the percentage base saturation to be very low, in some soils less than one per cent. The exchange positions on the plate-shaped clay particles (Figure 1) are largely occupied by H<sup>+</sup> ions. Only one per cent of the exchange positions are occupied by K, Mg, Ca, NH<sub>4</sub>, B, etc. When five to 20 tons of lime per acre were dumped on these soils, the nutrient balance was disrupted and decreases in yield resulted. The ratios of Ca/K, Ca/Mg, etc. were thrown all out of line.

Recent tests on these same soils have shown significant gains in both cane and sugar with relatively small applications of lime (200-400 lbs. Ca/A). With these smaller applications, the calcium requirement of the cane was met without disrupting the balance of other elements.

Calcium-potassium antagonism has been the subject of many investigations in recent years. Part of the difficulty in getting adequate quantities of potassium into the sugar cane plant, when grown on the gray hydromorphic and dark magnesium clay soils, is undoubtedly due in part to the high calcium saturation of the base exchange complex. The data in Table 2 show the inverse relationships between potassium, calcium and manganese in the leaf sheath at three levels of potash fertilization in Experiment 132 (b) AK X L at Grove Farm Company. Deficiencies of potassium existed in the check plots while luxury consumption of Ca and Mg occurred. As the rate of potash fertilization increased, the level of sheath potassium rose and the levels of Ca and Mg decreased.

### Potash-Nitrogen Interaction

Rates of fertilization of sugar cane in Hawaii have increased over the past several years. As soil and plant analyses have resulted in more balanced feeding, it has been found that higher amounts of nitrogen and potash can be effectively used under good growing conditions without adversely affecting the quality of the juice.

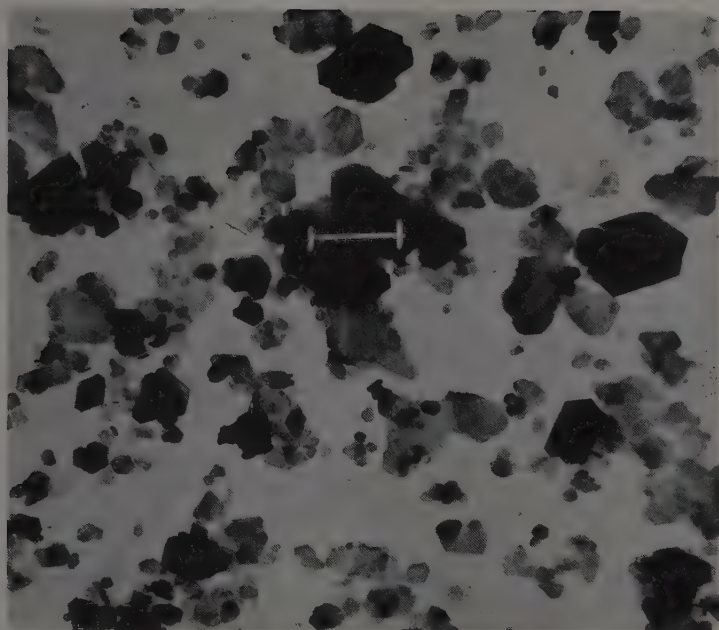


Figure 1. Plate-shaped particles of Kaolinite clay a principal constituent of Hawaiian soils.  
The measure indicates one micron.

TABLE 2. LEAF SHEATH LEVELS VARY WITH K<sub>2</sub>O FERTILIZATION  
Grove Farm Exp. 132 (b) AK × L

K <sub>2</sub> O Applied Lbs./AC.	Ca %	Mg %	N %	H <sub>2</sub> O %	Total Sugars	P %	K %
0.....	.494	.171	1.91	82.4	11.8	.102	1.07
200.....	.305	.080	1.79	84.8	6.5	.101	3.02
400.....	.275	.075	1.81	86.1	5.1	.101	3.85

Yield data from the 21 months' harvest of Olaa Sugar Company's test #104 AH × N × K, showed significant interactions on cane and sugar yields from nitrogen and potash fertilization (Table 3). Cane yields are not increased with increasing increments of one nutrient without a corresponding increase of the other. Balanced feeding of the two nutrients at the highest level of fertilization resulted in the highest cane yields. Similar results were obtained in the yields of sugar.

TABLE 3. POTASH-NITROGEN INTERACTION AT OLAA

Lbs. N/A	TCA			TSA		
	0	Lbs. K <sub>2</sub> O/A 200	400	0	Lbs. K <sub>2</sub> O/A 200	400
0.....	42.9	41.7	41.2	4.9	4.6	5.5
150.....	42.6	61.0	59.3	5.6	8.3	8.3
300.....	45.4	62.2	65.1	6.2	8.8	8.7
LSD.....		9.5			1.2	

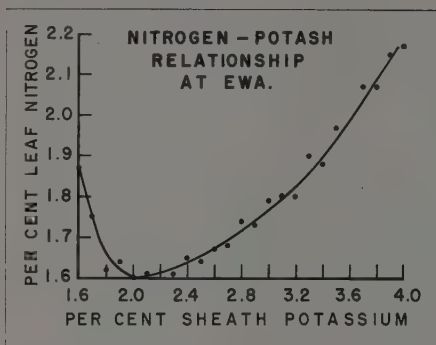
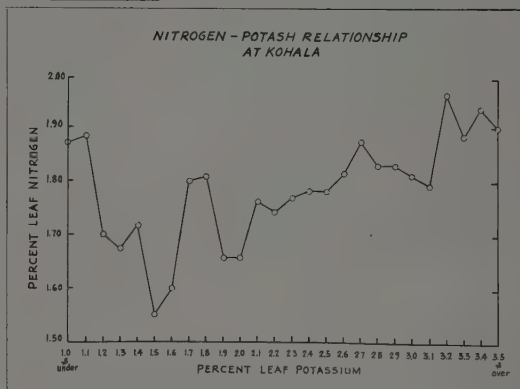


Figure 2

Figure 3



Crop log studies have also focused attention on nitrogen-potassium interactions in the plant. An examination of data accumulated over a period of six years at Ewa Plantation Company (2) revealed that when leaf sheath potassium dropped below 2.0 per cent, nitrogen accumulated in the leaf (Figure 2). Below this level, potassium became a limiting factor of growth. A review of data accumulated over a similar period at HC&S Co. (3) revealed the same relationship at that plantation. The level of sheath potassium where nitrogen began to accumulate was 2.2 per cent, which is very near the critical level established for this element by Clements (1). The critical level of sheath potassium is believed to be lower under some soil and climatic conditions. An examination of the records of crop logging over a period of seven years at Kohala Plantation (4) shows the potassium level at which unused nitrogen begins to accumulate to be about 1.5 per cent (Figure 3). These data are presented to show the variations to be expected under the different soil and environmental conditions present in the Islands. When other limiting factors of growth have been eliminated, nitrogen will not accumulate at the lower sheath potassium levels but will be utilized to produce more cane. This should raise the critical level of sheath potassium to nearly 2.0 per cent. The utilization of extra nitrogen and potash was realized at Olaa Sugar Company after phosphorus was eliminated as a limiting factor of growth. The harvest results of Olaa's experiment 103 AFP  $\times$  ANK are shown in Table 4.

**TABLE 4. PHOSPHATE AND HIGHER NITROGEN AND POTASH  
INCREASE YIELDS AT OLAA**

	Lbs.	TCA	Q.R.	Y% C	TSA
Amounts of $P_2O_5$ .....	0	62.4	9.2	10.9	6.8
(N = 24).....	400	72.5	9.1	11.0	7.9
	LSD	5.3	..	ns	.5
Forms of $P_2O_5$ .....	Raw Rock	68.1	9.2	10.9	7.4
(N = 8).....	Superphos	75.6	9.2	10.9	8.2
	Ammophos	73.8	9.0	11.1	8.2
	with Ca equalized				
	LSD	ns	..	ns	.6
	Lbs. N	Lbs. $K_2O$			
Amounts of N, $K_2O$ ..	175	350	66.5	9.3	10.8
(N = 16).....	225	450	73.4	9.0	11.1
		LSD	4.6	..	ns
				ns	.5

Significant increases in yields of cane and sugar were obtained for phosphate fertilization and for both superphosphate and ammophosphate with calcium equalized over raw rock phosphate. After the phosphate requirements had been satisfied, a gain of nearly one ton of sugar per acre was realized for an additional 50 pounds of nitrogen and 100 pounds of potash.

Balanced feeding controlled by soil and plant analyses is expected to help keep sugar-per-acre production climbing in Hawaii.

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## DISCUSSION

**H. F. Clements:** Dr. Humbert, I'd like to modify that statement I made before. Generally, when soils people talk about balance, they talk about ratios, calcium-magnesium and potassium-calcium ratios, and I thought that was what you were going to say. Now, what you said, I agree with 100 per cent, and I think it's the best argument in the world for the crop log, that is, to watch these deficiencies develop and feed accordingly. Now, when they used to talk in the old days about balanced feeding in the industry, you knew what that meant: 200 pounds of  $P_2O_5$ , 200 pounds of  $K_2O$ , 200 pounds of nitrogen. Now, that was strictly balanced, and yet obviously has no relation at all to what the plant is requiring, nor what one fellow puts on. Now, I have trouble with those guys along the Hilo Coast. Their potash is running so very high, they've got the notion that unless they put on just a little bit more potash than nitrogen their yields will be a flop. Well, the thing is, it's still a matter of providing the plant with a balanced nutrition. If that is what you always mean when you say a balanced nutrition, why I agree with you 100 per cent.

**G. O. Burr:** In the replacement of hydrogen with a very large dose of some one element like calcium, do you by any chance replace other elements than hydrogen and make them more leachable?

**R. P. Humbert:** Yes, you certainly do replace some of the elements that are on the exchange complex when you are applying large quantities of a divalent cation like calcium with a high activity. In the majority of cases, however, the hydrogen atoms are kicked off that exchange complex, which you realize by the climbing pH that you get from liming.

**B. Alexander:** Is there a suggestion that with high potash indices which you showed on the Ewa curve you might depress the yields, or has that relationship been worked out?

**R. P. Humbert:** That's a very interesting and challenging question. John Anderson asked me that very question at a meeting we had at Waipio, and I do not have an answer to it. I have examined the results of our amounts of potash tests over the last 15 years, and we find only three instances in all of those experiments, and there were some 400 of them, in which we got a significant decrease in sugar because of higher potash fertilization. Undoubtedly, there are reasons in this nutrient balance question again as to why those three showed decreases in sugar.

**W. Sanford:** I'd like to know, Roger, if there are any areas where you are getting response to calcium, where you are also getting response to magnesium?

**R. P. Humbert:** We have not harvested any replicated tests with magnesium as yet. We have tests installed and we have reason to suspect magnesium deficiency. Now, I mentioned magnesium toxicity in our gray hydromorphic and dark magnesium clay soils. We believe we also have the other extreme of magnesium deficiencies. In some of the work that Dr. Ayres and his group are doing, they have shown as low as 7 ppm exchangeable magnesium where the calcium levels are very much higher. Speaking as a soils man, we do like to see calcium-magnesium ratios of at least 1:1, and preferably a little higher, so that there is a very good possibility that we will have magnesium deficiencies in our analysis of tissues with the spectrograph. We believe that magnesium is in the picture on this leaf freckling problem.

**Herbert Gomes:** Was that decrease from excessive amounts of potash due to the quality of the juice, or was it less tons cane?

**R. P. Humbert:** Wamba, do you recall whether the significant differences in those few experiments were juice quality or tons cane per acre?

**Fred Denison:** Roger, I think I can answer two of them. They were both cane and quality—two on this island.

**H. F. Clements:** I'd like to add a little bit to that. I don't know how often you repeat an experiment like that, Fred, where you actually show a loss if you are irrigating adequately. If you're not irrigating adequately, you're going to run into trouble because of excess salt accumulation. But if you have normal irrigation, I don't think you will actually get a depression. The thing is, you're going to get less sugar credited to that field largely because the mill boys can't pick out enough sugar when it's loaded with potash.

**J. H. Payne:** In the low grade, you actually get muriate of potash crystallizing out which prevents the filtration of the low-grade molasses which gives less sugar produced.

**L. Thevenin:** In the Olaa experiment where the minimum application of nitrogen was 175 pounds and it went up to 225 pounds, and potash was applied at a generous 350 and increased to 450, there was a seven-ton-of-cane increase for those two combinations. What was that due to, nitrogen or potash? I think it was just nitrogen.

**R. P. Humbert:** That's a question we can't answer for the simple reason that we did not have a factorial with those two different treatments. I think Olaa will agree that it was probably combinations of both. Examinations of the logs of their fields show that when one is needed, the other is normally needed, too, in order to prevent a serious shortage of the other element.

**L. Thevenin:** Do we need the application of potash that high?

**R. P. Humbert:** Olaa has obtained significant gains for 800 over 400 pounds of potash per acre. I don't mean to imply that that quantity of potash is required to produce 100 tons of cane per acre. The best estimate at the moment is around 550 pounds of  $K_2O$  per acre for a 100-ton crop.

Leaching is very definitely a problem there. Dr. Ayres has shown that muriate of potash, potassium chloride, is the most easily leached form of potash.

**W. W. G. Moir:** In the six experiments in the coordinated test, we show very definitely a relationship of nitrogen in depressing both the potash and the phosphate in the cane plant either by Clements method of crop logging or crop logging by the Burr method, and the effect of one on the other is very, very marked. When you put them all together you tend to cover up the areas where you have greater deficiency with these elements which show up the figures to a greater advantage.

**Keith Tester:** With these heavy applications of potash, how late in the crop do you think you can apply the supplementary applications, and then expect to get increased yields?

**R. P. Humbert:** The analyses of the Amfac data seem to indicate that the most sensitive periods of defining subsequent requirements are in that period ranging from 8 to 10 or 11 months, so it seems that that would be the logical time in which to calculate the second-season requirements for nitrogen and for potash. I believe it would be possible, in case deficiencies existed, to obtain response from later applications, but as we improve our tools for defining the needs of subsequent applications, certainly a deficiency of a magnitude that would require applications later than that period should never be reached.

**Karl Berg:** I have a question relating to Keith's on practical feeding. At last December's Planters' meetings, Dr. Burr, if I recall correctly, made some statement to the effect that if your potash is near the danger line on the log, and if you're going to apply nitrogen, then you should apply some potash also. Could I have some comment on that, please?

**R. P. Humbert:** I think the experience in the industry is just exactly that. If you are approaching critical levels of potash and you have scheduled a nitrogen application, you certainly have to schedule potash along with it in order to keep that plant growing. You certainly would run into an acute potash shortage if you did not apply potash along with the nitrogen.

**Question:** I don't believe Mr. Tester's question has been answered yet. How late can you put it on?

**H. F. Clements:** That's been a major problem with us along the Hilo Coast. The tendency there, at first, was to put the potash along with the phosphate under the seed, and then not much more potash after that. With the normal leaching that occurs, there isn't much potash left when the plant starts to grow, and so we now withhold potash altogether from our first application and only put nitrogen and phosphate under the seed. On a ratoon, we put potash on with those two if there is need for them. But then, we've gotten completely away from these heavy slugs of potash all at one time. That is, this business of putting on 300 pounds of potash at one time, I think is just a waste of potash, and so we're practically limited now to 120 pounds. In fact, Kohala has gone to 90 pounds application as more or less standard because they seem to carry just about as well with the lighter application as with the heavy. But then, they keep on feeding, at least until 12 months of age. The point about putting on potash with nitrogen if the potash is close to the line, that's just standard practice along the Hilo Coast. If that is the case, then obviously at HC&S it would be silly because they're running 4.5 to 5 per cent potash. Along the Hilo Coast it is very different. Say your potash index is at 2.5 and you put on nitrogen and it is in a field that normally calls for potash. The chances are your next sample would show your potash down to 1.5 and your nitrogen standing still and not being used. Now, beyond 12 months of a 24-month crop, I don't think I have ever been able to see a response to potash. On nitrogen, yes, even at 15 months.

**R. P. Humbert:** The question of applying all of your potash with the seed—I don't think there is a single plantation in the industry, Harry, that is applying 300 pounds of its potash requirements with the seed. I think every one is in split applications. Now, to go back to Keith's question, we have no harvested experiments on the timing of potash applications in second season. We have with nitrogen, and where a nitrogen deficiency existed at Wailuku, and they put on extra nitrogen by airplane 5½ months prior to harvest, they got a significant gain in cane and sugar. To the best of my knowledge, around 12 months is the latest that has been tested with potash.

**Keith Tester:** I think all of us have this question of timing as far as potash is concerned. I know at Lihue many times, where we have generally a low potash level, we will apply potash, say up to 240 or 250 pounds, but will also apply a last supplementary application of nitrogen. As you continue to take your potash indexes, somewhere in the neighborhood of a year before harvest time, you will find your potash is still dropping. I think the practical question is: after you have applied all your nitrogen, and your nitrogen index is probably up fairly high while your potash index is maybe below 2, should you, after having put on 250 or 300 pounds of potash, apply supplemental nitrogen and potash at that time?

**R. P. Humbert:** To answer Keith's question further, we do have tests on time of potash applications. But it will be another year before those are harvested.

**H. F. Clements:** There is a point on that, too, Leonard. Ewa Plantation has some very poor fields as far as potash is concerned. Field 29, for example, is one illustration. Field 52 is another one. It's one of those pasty, black montmorillonitic soils. The last crop—this isn't a Grade A test—they actually fed that field 600 pounds of potash per acre, and they got the highest yield they ever got in the field. Now, the thing is that so far as I can see, there is no such thing as what might be considered a normal level. In other words, what does your crop need? When you consider that field produced about 115 tons of cane per acre, and that each ton of net cane contained about

six pounds of  $K_2O$ , well, you've got 720 pounds you're taking off the field, not counting your trash. So, to me, it's not at all unreasonable, Keith, that if your index is very low so that your plant isn't getting much, then you're just going to have to feed, and I don't think there is such a thing as a normal level in applied fertilizer at all.

**W. W. G. Moir:** As far as Lihue is concerned, if your sucker growth is great in that field, then you have to be extremely careful because by analysis, the suckers showed twice the level of potash that the primaries did under your conditions.

# HISTORY OF FERTILIZER USAGE IN HAWAII

RONALD Q. SMITH\*

In preparing a report on fertilizer usage in Hawaii, based upon the background of my 35 years of experience here, I thought it desirable to point out some of the incidents, experiments, and philosophies which I believe have had a bearing on the usage of fertilizer in the sugar industry. With these as a skeleton, the fill-in of the actual fertilizers used, in terms of raw materials such as animal by-products, chemical compounds and mixtures of compounds, as well as any other elements which are considered necessary for plant life, might make an interesting story.

## EARLY USAGES IN HAWAII

The "Planters' Monthly" is a record of the sugar industry beginning in 1882. The need for cooperation, which has characterized Hawaii's sugar industry, prompted the establishment of that journal. The first number recorded the belief that "The results of experiments with different kinds of fertilizers would supply interesting material for a letter to the MONTHLY." It went on to point out that information on fertilizers is a practical matter and of interest to planters "... especially to those whose area of cane land is limited. Fields near the mill which have been fenced, cleared and repeatedly planted are the most economical to cultivate if they will give a good yield. When such fields become exhausted, a good fertilizer of moderate cost would be of great value."

Apparently, some fertilizer tests had been established at that time. A few months later, Paukaa Plantation reported an increase of 1575 pounds in sugar production. The increase resulted from the use of 1000 pounds of bonemeal per acre. "The bonemeal cost laid in the furrows a trifle less than twenty dollars per acre. . . . We are applying bonemeal to ratoons this year and hope that a good result will follow."

At the fall meeting of the HSPA in 1882, there were further reports on fertilizers, as follows: "The use of fertilizer—chiefly bonemeal—has extended during the past year, and we are happy to report that it is now being tried on each island, chiefly with young plants, the results of which cannot, of course, be yet given, except in the case of Col. Austin of Paukaa, Hilo, who has matured one fertilized crop, and has kindly furnished the following statement of his experience. 'I have applied bonemeal, ashes from wood and trash burned together, and beach sand apparently composed largely of shells. From the latter no results so far as I could see. From ashes at 3000 pounds per acre, distributed as described below for bonemeal, result nearly as good in the plant, and apparently better in the ratoons as compared with 1000 pounds of bonemeal per acre.' "

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\* President, Pacific Chemical & Fertilizer Company.

## THE EXPERIMENT STATION TAKES A HAND

From 1882 to 1909 is a considerable interval, but it is interesting to note some of the reports of the managers of 1909. J. T. Moir of Onomea, an unirrigated plantation, reported: "Fertilizing consists of an application of 500 pounds of tankage along with the seed, and two applications of 400 pounds each of High Grade\* before laying past or finishing off. Along in March, April and May, we generally apply a 200 or 250 pound dose of sulfate of ammonia or nitrate of soda."

A summarization by the committee that year stated: "With the data at hand this (fertilization) can only be very briefly referred to. Climatic conditions differ; soils differ; no committee can say what should be done or how it should be done for these varying conditions, and each locality should govern itself accordingly.

"Nevertheless, there is one thing that stands out prominently in fertilizing our cane fields and which is generally applicable to all places. It is the value of ammonia as a sugar producer, and those in the past may not only have the gratification of knowing that they have derived great financial benefit from its use, but that the correctness of their judgment has been corroborated by tests made at the Experiment Station.

"It is considered the best practice, when applying ammonia as nitrate of soda, to do so in small doses. On the Ewa and Oahu plantations, on Oahu, and also on other estates this is applied in solution in the irrigation water and is a very efficient and economical form of application. Generally, the amount applied runs about 100 pounds and sometimes 150 pounds per acre for each application."

The practices reported above probably resulted from fertilizer experiments which were inaugurated on four plantations in 1905. In 1909, C. F. Eckart, then Director of the Divisions of Agriculture and Chemistry of the Experiment Station, HSPA, reported on these experiments:

"In Hawaii it has been amply demonstrated that fertilizers not only pay but pay well when they are judiciously applied and there is little doubt that the quantity and nature of the materials used often control to a large measure the crop returns. The fact that the planter may during favorable seasons influence the growth of his cane little or much according to the *judgment exercised by him* in this particular, should make the subject of fertilization a rich field for careful investigation on every plantation."

You will note that an important ingredient of success is the *judgment exercised* by the planter in using the information gained by experimentation.

You will note that organics, such as bonemeal, tankage, etc., played a very important role in the fertilizer programs. However, the inorganics, such as sulfate of ammonia and nitrate of soda, were gaining favor.

The trends to higher nitrogen fertilizers were accelerated as a result of Mr. Eckart's extensive report concerning an experiment at Hakalua.\*\* In that report, the tables given below were presented.

The application of nitrate of soda consisted of 300 pounds in each case.

In the discussion, much emphasis was placed on the value of the additional

\* High Grade Formula:

11 to 12% N from sulfate of ammonia and organic  
6 to 7% P<sub>2</sub>O<sub>5</sub> from bonemeal  
12% K<sub>2</sub>O from sulfate of potash

\*\* Planters' Record, XII, 111 (1915).

## WEIGHT OF ADDED ELEMENTS PER ACRE

### Hakalau Experiment reported 1915

Experiment	Without Nitrate Dressing			With Nitrate Dressing (300# N/S)		
	Nitrogen	Potash	Phos Acid	Nitrogen	Potash	Phos Acid
000.....				46.5		
600 lbs. Fertilizer.....	37.2	41.5	46.2	83.7	41.5	46.2
900 lbs. Fertilizer.....	55.8	62.3	69.3	102.3	62.3	69.3
1200 lbs. Fertilizer.....	74.4	83.0	92.4	120.9	83.0	92.4

## YIELDS OF CANE PER ACRE

### Hakalau Experiment reported 1915

Mixed Fertilizer Applied Per Acre	Yield of Cane, Tons		Increase Due to Nitrate	
	Without Nitrate	With Nitrate	Tons Cane	Percentage
000.....	13.46	25.39	11.93	88.6
600 lbs.....	23.13	28.91	5.78	25.0
900.....	22.48	39.48	17.00	83.8
1200.....	25.01	45.97	20.96	83.8
	21.02	34.94	13.92	68.2

nitrogen from nitrate of soda. Mr. Eckart stated that 300 pounds of nitrate of soda gave the same increase as 1200 pounds of fertilizer; namely, 11.83 tons of cane. However, by a different analysis one might have said that 1200 pounds of fertilizer, over and above 300 pounds of nitrate of soda, produced 20.96 tons of cane. The fertilizer picture might have been different if these experiments had been interpreted in the light of present-day knowledge. Certainly there appears to be a considerable interdependence of the elements used.

To point out the then trend in fertilizer usage, Eckart recorded the average formulae showing changes in the last ten years:

	Nitrogen	Potash	Phos Acid
Year 1904.....	6.3%	14.4%	8.7%
Year 1914.....	9.0	8.1	6.6

"In view of what the Hakalau and numerous other practical field tests have taught us, it appears probable that we might have obtained a larger yield in 1904 with about 300 lbs. of nitrate of soda or its equivalent of sulphate of ammonia than with the 900 lbs. of mixed fertilizer of the average Island formula of that day." To me, this seems like an unorthodox comparison. At least one plantation went on a wholly nitrate program.

On October 15, 1915, Carlton C. James\* reported at the annual meeting of the Hawaiian Chemists Association concerning changes which had recently been made in the composition of fertilizers, together with difficulties encountered as a result of these changes. He states: "In 1909, the Sugar Planters' Experiment Station issued Bulletin 29, concerning experiments with water-soluble fertilizers, and soon after radical changes were made in a great number of fertilizers, resulting in an appreciable increase in the nitrogen content. The nitrogen was usually divided equally among the different forms; sulfate, nitrate and organic. Later

\* Planters' Record, XIII, 315 (1915).

these formulae were changed from time to time, and for various reasons, so that the nitrogen was increased again. In order to make these increasingly concentrated fertilizers the organic matter had to give place to sulfate of ammonia and nitrate of soda." Thus these organics were progressively giving way to the inorganics.

## WORLD WAR I AND ITS EFFECTS

As a result of World War I, the supply of potash salts was cut off. We find potash recovered from kelp, molasses ash and cement dust being used. Nevertheless, there was a great shortage of potash, which was partially filled by Chile potash nitrate. Due to the demand for munitions, nitrate of soda was in short supply. Although the price of Chile potash nitrate was very high, \$150 to \$160 per ton, the leaders of local agriculture paid rather than be without both N and  $K_2O$  for their cane. Due to shipping difficulties, it was impossible to obtain phosphate rock from our regular suppliers, and we had to import high-cost rock from Idaho. The effects of the war continued until about 1921. The first cargo of potash salts from Germany after the war arrived about 1924. I do not know just how much the effects of the war reduced the use of the various fertilizer materials.

## A QUICK LOOK AT LIME

Throughout the records prior to 1915, there are many reports on the use of lime, either as the hydrate or the carbonate. Apparently on many of the plantations in the Territory, liming was standard practice and apparently so continued for some years thereafter. In addition, calcium is a major ingredient of bonemeal, phosphate rock, superphosphate, reverted phosphate and nitrate of lime.

## SUMMARY TO 1922

By 1922, we find the calcium requirements being satisfied, the organic nitrogen products giving way to inorganics such as sulfate of ammonia and nitrate of soda, nitrogen being used at a rate about three times that of  $P_2O_5$  and about four times that of  $K_2O$ .

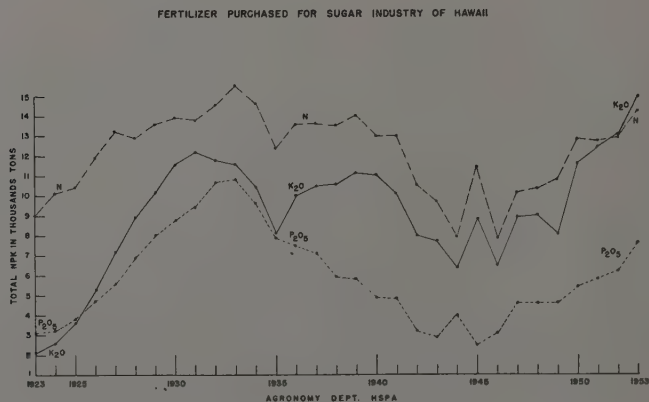


Figure 1

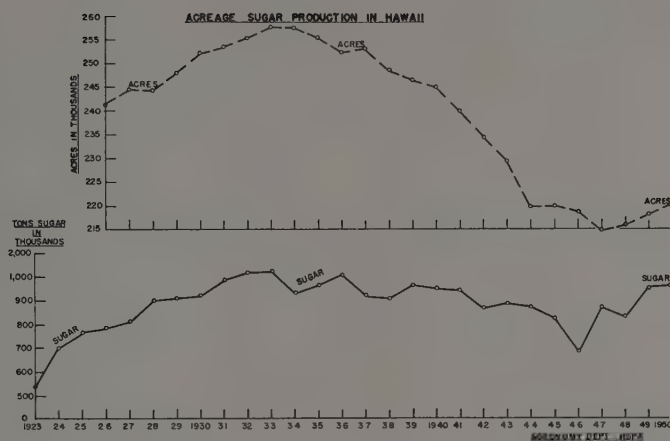


Figure 2

## EFFECTS OF THE PARADE OF NEW MATERIALS

One can obtain a reasonably good picture of the basic fertilizer consumption from 1923 to date by referring to Dr. Humbert's chart entitled "Fertilizer Purchased for Sugar Industry of Hawaii" (Figure 1). It is regretted that the picture for CaO is not available. Since I have been associated with the fertilizer industry during this period, I will draw on my memory as well as on recorded data in filling in pertinent information concerning fertilizer usage from 1923 to 1953 (Figure 2).

Before 1921, nitrate of ammonia and nitrate of lime had been imported from Norway. Later, they became available from Germany. Although the cost of nitrogen in the lime nitrate was high, a few of the managers of Norwegian extraction favored its use. Otherwise it never found much acceptance. During 1922, tests showed that, unit for unit, nitrogen from ammonium nitrate is as efficient as nitrogen from either nitrate of soda or sulfate of ammonia. During 1927, additional nitrogen carriers came into the market at prices competitive with the older nitrogen carriers. These consisted of ammonium nitrate sulfate, then known as Leunasalpeter (26 per cent N), Calurea (21 per cent N), and urea (46 per cent N). Also at that time, the unit cost of nitrogen in sulfate of ammonia fell below the unit cost of nitrogen in nitrate of soda.

In the potash department, a 60 per cent muriate of potash became available.

The manufacture of superphosphate in the Islands began in 1894, and has continued ever since with a somewhat cyclic acceptance of the product. During the second decade of the century and the early twenties, reverted phosphate found considerable use. This product was the result of an attempt to combine additional lime with super and at the same time supply a phosphate which was available but which remained unfixed in the soil.

In the twenties, the use of super accelerated at an unusual rate. Estimated requirements were on the low side. Capacity of the new chamber acid and superphosphate plants constructed in 1925 proved insufficient. Within a year after the construction, it was necessary to import acid in order to manufacture enough

super for local use. This continued until 1927-28 when ammophos became available at competing prices.

By that time apparently, calcium and other essential elements contained in super had been built up in the soil. Tests showed that, unit for unit,  $P_2O_5$  in ammophos produced yields equivalent to those from super.

During April 1928, the management of Pacific Chemical and Fertilizer Company (then Pacific Guano and Fertilizer Company) invited representatives of both the sugar and pineapple industries to receive a firsthand report on the possibilities of concentrating fertilizers by the use of some of these concentrated materials. In addition, substitution of sulfate of ammonia for nitrate of soda was suggested. The savings to the industry resulting from the concentration was estimated at \$250,000 per year. The agricultural representatives of the industries accepted the job of determining the advisability of the proposed changes. That they approved of the changes is evidenced by the following data taken from PC&F sales figures:

Year	Tons Fert.	N	$P_2O_5$	$K_2O$	Plant Food	Plant Food Fertilizer Ratio %
1928.....	147,038					
1929.....	162,238					
1930.....	163,666	18,132	10,442	12,012	40,586	24.79
1931.....	154,917	17,647	11,306	12,832	41,776	26.97
1932.....	125,057	16,949	11,226	11,308	39,483	31.57
1933.....	132,634	18,496	11,866	12,036	42,398	31.97
1934.....	124,583	17,678	10,039	10,474	38,241	30.70

While these figures represent total sales of fertilizer in the Territory, the ratio of concentration was equally applicable to sugar. The ratio of plant food to total tonnage of fertilizer in 1930 was 24.79 per cent, whereas in 1933 it was 31.97 per cent.

15,500 tons of superphosphate were sold in the Territory in 1930, whereas only 6450 tons were sold in 1933.

Ground phosphate rock had a period of considerable favor. PC&F sales were:

1927.....	2,757	1931.....	10,356
1928.....	4,931	1932.....	1,862
1929.....	10,374	1933.....	432
1930.....	10,855	1934.....	2,505

A popular sugar cane fertilizer was PS #3A made to the formula:

2% N	1½% Ammoniacal N
	½% Organic N
19¾% $P_2O_5$	16¾% Rock Phosphate
	3% Bonemeal
18½% $K_2O$	Muriate of Potassium

During the years 1930 to 1933, the transition from rock and super to ammonium phosphate was largely accomplished. During these years, those sugar plantations using sulfate of potash (estimated at about one-third of the area) changed their practice to the use of muriate and nitrate. Both Chile potash nitrate (14½ per cent N-15 per cent  $K_2O$ ) and potassium nitrate (13 per cent N-44 per cent  $K_2O$ ) were used in substantial quantities.

At about this time, the first anhydrous ammonia tests in Hawaii were installed.

While the concentrated fertilizer program delivered the three plant nutrients N, P and K, it should be noted that it also eliminated other necessary elements

which had heretofore had a free ride in the lesser concentrated materials. Calcium was practically eliminated from the picture. A considerable amount of research was directed toward determining the possible effects of elimination of calcium and minor elements from the fertilizer program. Verret\* reported the results of 19 lime experiments. He stated: "We find little or no evidence that the lime has affected the cane tonnage, but it would seem to be more than a striking coincidence that in practically all cases the quality ratio was slightly better in the no lime plots." He sounded a warning, however, that "Lime is one of the absolutely essential nutrients of plants. We must also concern ourselves with maintaining adequate reserves of calcium."

## PRICES AND REGULATIONS INFLUENCE USAGES

The Sugar Act passed early in the Roosevelt Administration had a very marked effect on fertilizer usage. How to bring our production into conformity with the sugar quota was a pressing problem. Eventually the area in cane was reduced. During 1933-34, there were approximately 255,000 acres in cane. By 1940 the area was down to 235,110 acres. During the war years further forced reduction took place. In 1944 there were 220,000 acres and a low of 206,550 acres was hit in 1948. In his annual report for 1948, J. E. Russell, retiring President of the HSPA, called for maximum production of sugar. Since then, the area in production has increased steadily until it is again in excess of 220,000 acres. Naturally the area in use had a marked effect on the total fertilizer used.

The story of Chile potash nitrate is interesting. Due to the economic pressures of the early thirties, Chile offered its potash nitrate at a price which brought the cost of the nitrogen and potash contained therein to the level of the cost of nitrogen in sulfate of ammonia and of potash in muriate of potash. As a result, consumption of Chile potash nitrate on sugar plantations increased until the War, when shipping difficulties caused a decline in its use. In 1937, some 30,000 tons were used. This demonstrates how pricing policies affect fertilizer usages.

## EFFECTS OF WORLD WAR II

Chile potash nitrate was a war casualty. An international committee allocated fertilizer materials to essential crop areas. As a result, Hawaii was limited principally to sulfate of ammonia, ammonium phosphate and muriate of potash. In 1945, ammonium nitrate was added.

The war effort depleted hands for continuing the fertilizer test plots on plantations. By 1946, the managers who recognized the possibility of excessive soil depletion began increasing applications of  $P_2O_5$  for insurance, rather than await the outcome of fertilizer tests.

The reduction in acreage due to war operations accounted to a great extent for the low consumption level of those years.

### Labor Disturbances

The 81-day strike on sugar plantations in 1946 and the six-month longshoremen's strike of 1949 both left an imprint on the fertilizer consumption picture.

### Per Acre Usages

With the exception of some war and post-war years, consumption of N and

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\* Planters' Record, XXXVII, 17 (1933)

K<sub>2</sub>O remained at about the 1934 level. Another exception occurred in 1935, when the effects of the Sugar Act dominated practices.

P<sub>2</sub>O<sub>5</sub> shows a different picture. It appears that we dropped from a high of 87 pounds P<sub>2</sub>O<sub>5</sub> per acre in 1933, to a low of 27 pounds per acre in 1942, and of 23 pounds per acre in 1945. If sugar cane absorbs about 100 pounds of P<sub>2</sub>O<sub>5</sub> per acre per crop, it would appear that, for the period 1933 to 1945, we did a fairly complete job of using up the soil's reserve of that element. The judgment which dictated this procedure is akin to the one which sometimes has sought shorter and shorter cropping as a means of making sugar quotas.

Unfortunately, we have no similar figures for calcium or for the several minor elements. However, we know that with the advent of the concentrates, calcium was practically eliminated from the fertilizer program. Approximately 100 pounds of CaO are absorbed by an acre of cane per crop. It is no wonder that superphosphate, which contains 32 per cent CaO, is now showing such remarkable results.

### THE ACTIVE FIFTIES

During 1950, a plantation on Maui began applying fertilizers in liquid form. The liquid fertilizers consisted of urea-ammonia solutions, straight urea solutions, straight muriate of potash solutions and some mixtures. For a short time, ammonium nitrate and ammonia solutions were used.

At the same time, anhydrous ammonia became available in limited quantities. A plantation on Oahu and one on Maui undertook to apply this form of ammonia both in irrigation water and by injection into the soil. This continued through 1953.

Due to the very substantial increase in production of anhydrous ammonia on the mainland and a consequent desire by producers to sell anhydrous as such (not converted to other products), it became possible during the latter part of 1953 to prepare to handle large volumes of ammonia. The most economical method of transporting and handling this product is in the form of 20 per cent aqua ammonia. It is expected that about 30,000 tons of aqua ammonia will be used by the sugar industry during 1954. This is another example of economics influencing fertilizer usages. It also demonstrates the ability of the sugar industry to change practices quickly.

Information gained from new techniques, together with a broadened recognition of the role of fertilizers, made second-season applications of fertilizers desirable. Air application was the answer. However, the mechanical conditions of fertilizers greatly effect their flowability. After working with a producer for three years, we now have suitable muriate of potash. Pelleted urea is also available. As a result, there is increased use of both N and K<sub>2</sub>O.

The fifties have initiated a period of increased use of fertilizers and active search for improved physical and chemical forms of these materials. Calcium and the minor elements are receiving the attention due them.

Superphosphate and phosphate rock are rapidly taking a dominant position in the fertilizer picture. This is due largely to the results of recent experiments and a realization of the amount of lime and other elements which get a free ride with super and rock.

It is worthy of note that in 1952 the consumption of K<sub>2</sub>O exceeded the consumption of N for the first time. We now find that N and K<sub>2</sub>O are applied at about

equivalent rates, and that these values are about 1.9 times as much as the  $P_2O_5$  used. This is a tremendous change from the 1923 picture. This does not mean that each acre is treated like every other acre, but refers only to the over-all picture.

A useful history of fertilizer usage in Hawaii should provide material for development of a background for present and future personnel who direct sugar cane production.

A determination of minimum fertilizer requirements is a tool which assists management in exercising the judgment necessary for successful plantation operation. The final picture of fertilizer usage on cane is the result of the combined thinking and effort of the people of the day. Even today, additional history is shaping up as a result of the efforts of our contemporaries.

With the new tools which they have developed and the vigor with which they pursue their work they cannot help but produce a brilliant record. Signs which are well discernible indicate this will be so. I extend congratulations to these men of today and tomorrow.

## DISCUSSION

**W. M. Moragne:** How far away are we from a complete liquid fertilizer?

**R. Q. Smith:** Well, it appears to me that you probably don't want a complete liquid fertilizer, but if you do, it wouldn't be difficult to have one. It's a matter of cost, again.  $P_2O_5$  probably would not be desirable in there if you're going to put it on the soil. Now, the leaf application, or foliar application, of  $P_2O_5$  as pointed out this morning, might be quite a different thing. However, so far as muriate and nitrogen are concerned, those can be had at any time that you wish to do it, and some plantations are putting on liquid fertilizers. Wailuku has been putting on liquid fertilizers for four years. So, it's a matter of the economics of the situation. Any time you handle muriate of potash, you put more money into it. Eventually, if you do it on a sufficient scale to justify setting up for it, it can be had. We are working on one right now for Wailuku, which could be for anyone. Some of the plantations have gone into applications of muriate of potash and dissolving it on their own plantations. I think Oahu has a setup like that—carry out the solids to .60 per cent and make it into 15 or 20 per cent—I forget just what it was.

**W. M. Moragne:** In other words, when you have a liquid fertilizer and add to it nitrogen, phosphate and potash in the quantities that you want, when could we call you up and get a complete liquid fertilizer?

**R. Q. Smith:** Just as soon as the sugar industry is ready to do it on a sufficient volume to set up to do it. Ammophos goes in solution and you get phosphoric acid. We make phosphoric acid here—there's nothing new about it, if that is your desire. What I would like to see is something about quantity of any one type of liquid solution. Now you can't just willy-nilly take out  $P_2O_5$  in a liquid form and change to some other ion because you will have precipitation. You can get the equivalent of diammonium phosphate into a liquid. Now, when you add potash you will have to add more water, and it's the quantity that you'll need to apply that really sticks you.



# FORMS OF FERTILIZER MATERIAL IN RELATION TO EFFICIENCY OF UTILIZATION

A. S. AYRES\*

The ability of a crop to utilize added fertilizer is a function of the availability of the fertilizer per se and of the environment in which it is placed. The fertilizer may be one that dissolves instantly in the soil solution and is thus immediately and wholly available to the crop, or one that is only slowly brought into solution, or one which may even require chemical transformation in the soil before the crop can make use of it. Among the factors of the environment which may affect the utilization of a fertilizer by the crop are fixation, leaching, degree of deficiency of the element in question, volatilization, pH, physical condition of the soil, placement of fertilizer, moisture, temperature, and antagonism of other ions.

In the following discussion, consideration is limited essentially to those carriers of nitrogen, phosphorus, and potassium, which are currently in use on the sugar plantations of the Hawaiian Islands.

## NITROGEN

Nitrogen in many forms has been used on the plantations, one form, in turn, giving place to another. As elsewhere, cost per unit of nitrogen has been the principal determining factor. Four carriers of the element are presently employed, namely, ammonium sulfate, ammophosphate (principally of the 11-48 type), urea, and aqueous ammonia.

### Availability

These fertilizers are all soluble in water and hence are absorbable upon contact with the plant roots. All enter into the exchange regime of the soil, whereby the ammonium portion of the fertilizer is in some degree adsorbed in a non-leachable, yet available, form. With urea, this reaction occurs only after hydrolysis to ammonium carbonate has taken place.

### Leachability

Carriers of nitrogen are not equally susceptible to leaching in Hawaiian soils. This has been demonstrated by Sherman and his associates (10) who passed solutions of several nitrogen fertilizers, each containing 1000 ppm N, through columns of two Oahu soils and analysed the resulting leachates. The results are shown in Table 1.

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\* Senior Agronomist, Experiment Station, Hawaiian Sugar Planters' Association.

TABLE 1. NITROGEN IN LEACHATES

Nitrogen Carrier	Soil	
	Low Humic Latosol (Poamoho)	Dark Magnesium Clay (Lualualei)
	ppm	ppm
Sodium nitrate.....	691	...
Ammonium sulfate.....	424	631
Ammonium nitrate.....	370	545
Monoammonium phosphate.....	238	339
Diammonium phosphate.....	30	56

Two of the fertilizers employed on the sugar plantations were included in the study, namely, ammonium sulfate and (mono)ammonium phosphate. Of these, the latter is seen to be much less liable to leaching than the former.

How urea and aqua ammonia fit into the picture is not known. Urea, since it is converted in the soil to the carbonate form, would be expected to be less susceptible to leaching in acid soils than ammonium sulfate. Because of its basic property, this should be true also of aqua ammonia. In Table 2 is shown the vertical distribution of nitrogen in the soil at two locations in the cane line following normal irrigation with aqua ammonia applied at the rate of 60 pounds N per acre. The test was conducted by the joint staffs of this laboratory and Waipio Substation on a slightly acid soil of the Molokai Family.

TABLE 2. AMMONIUM NITROGEN IN SOIL

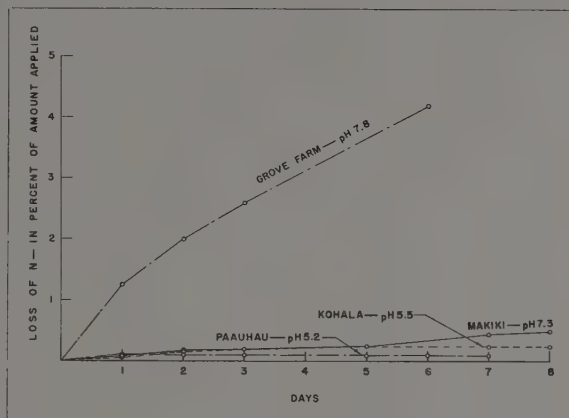
Distance From Point of Application	Depth of Sample	Unfertilized*	Fertilized Test #1	Fertilized Test #2
feet	in.	ppm	ppm	ppm
25	0-1	6	465	465
	1-3	14	120	140
	3-6	25	43	67
	6-9	25	46	13
	9-12	14	39	2
	12-24	1	1	5
	24-36	0	0	0
100	0-1	2	395	460
	1-3	4	120	53
	3-6	13	80	0
	6-9	6	16	0
	9-12	..	15	0
	12-24	0	4	0
	24-36	0	0	0

\* Samples taken in adjacent unfertilized cane line.

The nitrogen appears to have been held principally in the top three inches of soil and essentially all of it within the surface nine inches. This placement was observed despite the fact that the volume of irrigation water was sufficient to penetrate to a depth of several feet. Similar results have subsequently been obtained in a more thorough study of the subject by Vorfeld (12) at Oahu Sugar Company.

It should perhaps be noted that studies of the leachability of ammonium carriers can lead to erroneous conclusions regarding their retention by the soil. Once the nitrogen of the fertilizer has been converted through the media of soil bacteria from the ammonium to the nitrate form, it is highly susceptible to leaching, regardless of its origin. It will be noted that sodium nitrate stands at the top of the list in Table 2. As Sherman (10) has suggested, however, there may well be a relationship between the retention of a particular ammonium salt by the soil and the rate of conversion to the nitrate form.

Figure 1



## Fixation

The ammonium ion, being of the same size as the potassium ion, and possessing the same charge, behaves in the soil in several respects as does the potassium ion. Thus, soils that fix potassium may also fix ammonium.

So far as is known, no work has been done on the fixation of ammonium by Hawaiian soils. It is possible, however, to reason by analogy in the matter, on the basis of our knowledge of the potassium-fixing abilities of Hawaiian soils. Hagiwara (5), in a recently completed study of the subject, found no conclusive evidence of potassium fixation except in the dark magnesium clay group of soils. Even in these, fixation was not severe. On this basis, ammonium fixation would not be considered to be a problem of great importance in Hawaiian soils.

## Volatilization

Nitrogen in the form of ammonia is a gas. A condition of the environment which permits the conversion of ammonium to ammonia may result in loss of nitrogen to the atmosphere. With the solid forms of ammonium fertilizers such loss would be anticipated only on alkaline soils. Figure 1, prepared from data obtained in this laboratory, shows losses of nitrogen by volatilization from moist soils of various pH values which had been treated with ammonium sulfate at the rate of 60 pounds N per acre.

Losses for the periods indicated are very small in the acid and neutral ranges. At the higher pH, a condition resulting from the presence of coral sand (calcium carbonate), the loss is substantial.

Preliminary tests indicate that losses of ammonia resulting from the addition of urea to alkaline soils may be even greater. 11-48 ammophos does not appear to suffer loss of nitrogen upon addition to calcareous soils. From this standpoint, it should prove a satisfactory source of nitrogen for this type of soil.

Ammonia is very soluble in water—710 volumes in one volume of water at 20° C. and 760 mm. The high solubility of the gas, coupled with the high degree of dilution which obtains where ammonia is applied to sugar cane in irrigation water, should favor its distribution by this method. However, volatilization losses from irrigation water have not as yet been adequately evaluated under local conditions.

The application of aqua ammonia directly to the soil may result in loss, especially where the application is made to the surface of the soil. In Table 3 are shown losses of ammonia by volatilization, as measured in this laboratory, from three widely varying types of soil to which aqua ammonia had been applied at the rate of 60 lb. N per acre. Moisture contents of the soils were those prevailing at the time they were brought from the field.

**TABLE 3. CUMULATIVE LOSSES OF AMMONIA FROM FIELD MOIST SOILS  
in Per Cent of Amount Applied**

Soil	Time	Loss	Soil	Time	Loss	Soil	Time	Loss
	min.			min.			min.	
Humic	30	5.5	Humic	30	4.8	Low Humic	30	4.9
Latosol	60	6.8	Ferruginous	60	6.6	Latosol	60	6.6
(Hamakua)	90	7.5	Latosol	90	7.6	(Makiki)	90	7.9
	120	7.9	(Puhi)	120	8.3		120	8.8
	150	8.3		150	9.0		150	9.5

Losses of nitrogen are seen to be appreciable even for the brief periods during which the tests were conducted. It is apparent from the data that the type of soil has little effect upon the loss.

Cane trash, frequently present in considerable amounts in fields of young unirrigated cane, may increase the loss of nitrogen where aqua ammonia is applied on the surface. In Table 4 are contrasted losses of ammonia from the bare surface of an Olaa soil treated at the rate of 60 lb. N per acre, and from another portion of the same soil similarly treated, but to the surface of which a small quantity of cane trash had first been added.

**TABLE 4. CUMULATIVE LOSSES OF AMMONIA FROM BARE AND FROM  
LITTERED SURFACES  
in Per Cent of Amount Applied**

Soil	Time	Without Trash	With Trash
	min.		
Hydrol Humic Latosol	30	3.6	13.6
Hilo Family (Olaa) pH 5.0	60	5.3	16.2
	90	6.4	17.5
	120	7.3	18.3
	150	7.9	18.9

From the data, it is evident that applying aqua ammonia to surfaces littered with cane trash would be a wasteful process.

The effect of the moisture content of the soil upon the loss of nitrogen resulting from surface applications of aqua ammonia is illustrated for two soils in Table 5. In each comparison, one sample was in the air-dry condition, the other at field capacity. As before, ammonia was applied at the rate of 60 lb. N per acre.

**TABLE 5. CUMULATIVE LOSSES OF AMMONIA FROM AIR-DRY SOILS  
AND FROM SOILS AT FIELD CAPACITY  
in Per Cent of Amount Applied**

Soil	Time	Air-Dry	Field Capacity	Soil	Time	Air-Dry	Field Capacity
	min.				min.		
Low Humic	30	8.9	4.0		30	7.7	5.1
Latosol	60	11.6	5.9		60	10.2	7.9
(Waialua)	90	12.8	7.0	(Kahuku)	90	11.5	9.8
pH 6.3	120	13.3	8.0	pH 7.5	120	12.4	11.4
	150	13.6	8.9		150	13.1	12.5

Volatilization losses from the wet soils are seen to be less than from the corresponding dry soils. The effect is more pronounced with the Waialua soil.

Placement of ammonia at a slight distance below the soil surface greatly reduces the loss of ammonia whether the soil be wet or dry. This is illustrated in Table 6. The subsurface application was made about an inch below the surface.

TABLE 6. CUMULATIVE LOSSES OF AMMONIA FROM SURFACE AND SUBSURFACE APPLICATIONS OF AQUA AMMONIA in Per Cent of Amount Applied

Soil	Moisture Status	Time min.	Surface	Subsurface
Kahuku	Air-dry	30	7.7	0.2
		60	10.2	0.5
		90	11.5	0.9
		120	12.4	1.3
		150	13.1	1.7
Kohala	Air-dry	30	7.4	0.3
		60	10.2	0.6
		90	11.9	1.0
		120	13.1	1.3
		150	14.0	1.6
Kahuku	Field capacity	30	5.1	0.1
		60	7.9	0.2
		90	9.8	0.3
		120	11.4	0.4
		150	12.5	0.6

The desirability of applying the aqua ammonia beneath the soil surface on the unirrigated plantations is apparent from these results.

### Field Experiments

Field experiments carried out on the sugar plantations on soils deficient in nitrogen appear in general to show that one form of the element is about as effective as another. Aqua ammonia has been introduced into the picture so recently that the results of Grade A field tests comparing this with other forms of nitrogen are not available.

### Recovery of Applied Nitrogen

The recovery of a fertilizer element may be defined as the amount of the element taken up by a fertilized crop, less that taken up by an unfertilized crop under otherwise similar conditions in relation to the amount of fertilizer applied. For nitrogen, this recovery is comparatively high. Millar and Turk (7) give a general figure of 50 per cent for ammonium sulfate and sodium nitrate. Presumably the figure for other soluble nitrogen compounds would be equally high. Still higher values for the recovery of nitrogen are sometimes cited.

## PHOSPHORUS

Ground bone, often steamed or acidulated to increase availability, appears to have been the first commercial phosphate fertilizer. At the present time, almost innumerable phosphate carriers are on the market, many of them by-products of low phosphate content.

In Hawaii, some of the earlier used phosphate fertilizers, such as bone meal and reverted phosphate, have all but disappeared. Present practice is essentially restricted to the use of superphosphate, raw rock phosphate, and the ammoniophosphates, the last principally of the 11-48 type.

### **Availability—In Absence of Soil**

Superphosphate and ammophos may be considered to be completely available to plants when employed in culture media. Presumably this is true also when applied to soil, insofar as fixation is prevented by banding or by mixing with organic materials to prevent contact with the soil.

Rock phosphate, depending somewhat on its source and its degree of fineness, is comparatively unavailable to many crops and only slowly available to those that can use it. Gow and Ward (4), at this Experiment Station, compared availabilities to sugar cane of a number of soluble and insoluble phosphates in cultures of quartz sand. A continuous drip technique was employed with the nutrient solution buffered at about pH 7.0. During the first six months, plants treated with rock phosphate suffered a severe phosphorus shortage; in fact, they appeared little, if any, better than the check plants. Thereafter, however, they commenced to pick up and at the conclusion of the test, at 12 months, they had produced about as much dry weight as any of the treatments.

This lag in availability of rock phosphate has been apparent in many field experiments on the plantations. It has also been commonly observed elsewhere, and for this reason rock phosphate is considered a more satisfactory source of phosphorus for long-season crops and perennials than for short-season crops. Despite this shortcoming, rock phosphate comprises a substantial portion of the total amount of phosphate sold for direct application to the soil in the United States and its Territories—16 per cent in 1951, according to Rogers, Pearson and Ensminger (9).

### **Availability—In Soil**

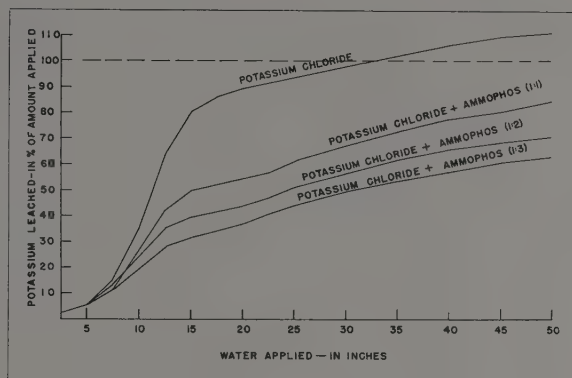
The availability of soluble phosphates is greatly reduced by contact with soil. A great deal of evidence has accumulated to show that the availability of adsorbed, or fixed, phosphorus is not constant for a given soil, but rather decreases with time. The current viewpoint, as expressed by Kurtz (6) in 1953, is that for a brief period of possibly a few months following the addition of a soluble phosphate to the soil, and subsequent adsorption, the phosphorus thus held can be readily utilized by most crops. With time, however, this phosphate is gradually transformed into increasingly less available forms.

Rock phosphate, being insoluble in water, is not adsorbed by the soil except as it is brought into solution by soil acids. This process may be a very slow one where the phosphate has been localized, as is evidenced by the fact that under these circumstances particles of the phosphate have been detected in soil samples taken in the cane line as long as two years after the phosphate was applied. Upon solution in the soil, rock phosphate is subject to the same adsorption processes that take the soluble phosphate fertilizers out of solution.

### **Liability to Leaching**

Hawaiian soils, with few exceptions, are clay soils, and adsorption of soluble phosphates is both rapid and complete (1). These phosphates are not, therefore, subject to leaching, even in areas of heaviest rainfall. Nor is rock phosphate subject to leaching, since it is insoluble in water. Soil phosphates may thus move only mechanically. Serious loss of phosphate may be caused by erosion, which, in some instances, carries off large quantities of fine particles of soil made rich in phosphorus by fertilization.

Figure 2



## Secondary Considerations

A factor of no consequence on many soils, but of great importance on others, is the calcium content of phosphate fertilizers. Large areas of Hawaiian sugar cane soils are so highly leached that they contain less than 100 ppm of exchangeable calcium—a value which there is reason to believe is not far from the critical level for this element with respect to sugar cane.

Where phosphate is applied to soils very low in calcium, a calcium-containing phosphate is to be preferred unless calcium is to be supplied to the soil from some other source. Super and rock phosphates contain, respectively, about 30 and 40 per cent of CaO. The ammonium phosphates contain only very small amounts of calcium.

An aspect of phosphate fertilization seldom given consideration is the effect of the particular carrier on the constituents of other fertilizers applied at the same time. An instance of this is seen in the work of Ayres and Hagihara (5), who showed that the simultaneous application of ammophosphate and potassium chloride to soils prone to loss of the latter by leaching resulted in greatly reduced loss of potassium. It was found, moreover, that for a given application of potassium, the loss of K was less the greater the amount of phosphate added. This is illustrated in Figure 2 in the case of a hydrol humic latosol from Olaa. Other soluble phosphates, super and treble super, were found to exert no retarding effect upon the loss of potassium chloride. A differential factor of this nature could have substantial practical significance. It could also have considerable bearing upon the interpretation of the results of field fertilizer tests.

## Utilization in Relation to Method of Application

Soluble phosphates being adsorbed by the soil, it seems logical to reduce to a minimum contact between the soil and added fertilizer. The most common ways of achieving this objective are by banding or by drilling the fertilizer into the soil. These means of applying soluble phosphates have universally been found to give more satisfactory results than broadcasting.

With rock phosphate, the issue is less clear. If this material must be brought into solution by soil acids before it can be absorbed by the cane plant, then localization of the fertilizer hardly seems defensible, except possibly on the grounds of greater immediate accessibility to the roots. Certainly the solution of rock phosphate would be expected to take place more rapidly when mixed with

the entire tilled layer, as it is when broadcast and plowed in, than when banded or otherwise restricted. Experience elsewhere has shown that phosphates of low solubility are most effective when broadcast and worked into the soil.

### **Choice of Carrier—In Relation to pH of Soil**

*Ammonophosphate:* Experience generally (9) appears to indicate that ammonium phosphate, because of its high solubility and residual acidity, is a good source of phosphate on alkaline soils. On highly leached Hawaiian soils, this carrier has sometimes failed to produce as large increases in sugar as superphosphate. This is explainable in certain cases on the basis of the calcium contents of the two fertilizers.

*Superphosphate:* Superphosphate, the first of the soluble phosphates, although sometimes equalled in effectiveness by other carriers, appears rarely to have been beaten. Elsewhere, as in Hawaii, it remains the standard against which other phosphate fertilizers are evaluated, regardless of soil type.

*Rock Phosphate:* Much controversy revolves around the use of this material which, because of its lower cost, is a tempting source of phosphorus. Agreement appears to be general that on alkaline soils it is of little value. On acid soils, it has frequently been found to be an effective source of phosphorus, and sometimes the most economical form on the basis of plant response.

### **Immediate and Future Needs for Phosphate**

Phosphate fertilization may be viewed from the standpoints both of immediate need and of permanent agriculture. Thus, soluble phosphates may be employed to meet present crop requirements, leaving the less expensive, slowly available rock phosphate to care for future needs. For the latter purpose, rock phosphate has sometimes been applied on the plantations in very large single applications.

### **Raw Rock vs. Superphosphate in Field and Other Tests**

Sherman (10) reported "excellent growth" of alfalfa from rock phosphate on acid, high phosphate fixing Hawaiian soils. It may be added that this crop is considered to be a "strong" feeder on rock phosphate.

Ayres (2) compared availabilities to sugar cane of raw rock, reverted and superphosphates on a Manoa (humic latosol) subsoil of pH 4.6, which had been shown by chemical test to be deficient in available phosphorus. The test was conducted in large ( $2 \times 2 \times 2$ ) containers and the phosphate, in each instance, was intimately mixed with the top six inches of soil. Harvested at 13 months, all treated pots contained 10 times as much millable cane as the pots receiving nitrogen and potassium alone.

Although, in this experiment, rock phosphate was fully as effective a source of phosphorus as superphosphate, the manner in which the phosphates were applied should not be overlooked. Mixing with the soil would be expected to render rock phosphate more effective than would localization, although the reverse would likely be true for superphosphate.

Many field experiments comparing super and raw rock phosphates have been conducted on the plantations, but the information to be gained therefrom is limited. As elsewhere, such tests were often conducted on soils not shown to be deficient in phosphorus. Equality of yields under such circumstances does not necessarily prove one form of phosphorus to be as effective as the other, but may

indicate simply that both were superfluous. Moreover, the matter of the pH of the soil, so important with respect to rock phosphate, was in many cases quite overlooked.

The results of field experiments over the years seem to indicate that on the more acid soils rock phosphate may be an effective source of phosphorus for sugar cane. There appears to be little in these tests, however, to support its use on soils of higher pH. The comparative effectiveness of super and rock phosphates on soils in the pH range of 6-7 at Pioneer Mill is summarized by Moir (8) in the following words: "In a series of five experiments harvested 22 times, it has been clearly shown that superphosphate was distinctly superior to reverted and raw rock phosphates. Even when 300 pounds of phosphate per acre were used, the difference in cost of super and raw rock . . . would be made up three times in the price of increased sugar per acre obtained from super over raw rock."

### **Recovery of Applied Phosphate**

Recovery of phosphate by crops is very small as compared with that of nitrogen, for example. Estimates seldom exceed 10-20 per cent for a single crop. Calculation of the recovery of phosphorus from data obtained by Stewart (11) in a study of nutrient uptake by sugar cane gave a figure of 14 per cent.

## **POTASSIUM**

Except for experimental purposes, the use of potassium on the sugar plantations is restricted entirely to the chloride (muriate). This is in striking contrast to the practice on the pineapple plantations, where the sulfate is employed exclusively, its use seemingly dictated by fear of harmful concentrations of chloride.

Although not a part of plantation practice, the sulfate and phosphates of potassium will also be discussed briefly since, in some Hawaiian soils, they are utilized more efficiently than the chloride.

### **Availability**

Potassium chloride is very soluble in water. The sulfate and (ortho)phosphate are also soluble, although progressively less so than the chloride. Upon addition to a moist soil, all three are immediately available to plant roots.

### **Fixation**

As already noted, Hagihara (5) was able to demonstrate measurable fixation of potassium only on the dark magnesium clay soils, maximum fixation amounting to about 20 per cent of the amount applied. The results were the same for the phosphate ( $\text{KH}_2\text{PO}_4$ ) as for the chloride. Work was not done with the sulfate, but there appears no reason to believe that results would have differed with respect to this salt.

### **Leachability**

Potassium chloride is very susceptible to leaching in some Hawaiian soils. On such soils, Ayres and Hagihara (3) showed that the sulfate of potassium was leached less readily than the chloride, and the phosphate least of all. This differential behavior of the three salts is illustrated in Table 7, taken from the paper to which reference has been made.

TABLE 7. CUMULATIVE LOSSES OF POTASSIUM UPON LEACHING  
in per cent of amount applied

Great Soil Group	Potassium Salt	Potassium Losses with Various Applications of Water							
		10"	15"	20"	25"	50"	75"	90"	100"
Humic latosol	KCl	17.6	56.6	75.4	84.4	90.6	90.8	...	93.5
	K <sub>2</sub> SO <sub>4</sub>	0	0	1.5	3.9	52.9	78.6	...	88.7
	K <sub>3</sub> PO <sub>4</sub>	0	0	0	0	0	17.5	...	32.6
Hydrol humic latosol (Pepeekeo)	KCl	0.9	30.9	56.5	65.3	70.4	80.7	...	87.9
	K <sub>2</sub> SO <sub>4</sub>	0	0	0	0	44.0	74.8	...	86.8
	K <sub>3</sub> PO <sub>4</sub>	0	0	0	0	0	19.3	...	33.2
Hydrol humic latosol (Olaa)	KCl	12.6	64.0	89.6	92.5	97.4	99.5	99.8	...
	K <sub>2</sub> SO <sub>4</sub>	0	6.1	29.1	49.9	91.8	96.4	96.8	...
	K <sub>3</sub> PO <sub>4</sub>	0	0	0	0	12.6	23.9	29.0	...

It will be seen that substantial losses of potassium from the chloride occurred before there was any loss from either the sulfate or phosphate. Moreover, heavy losses were sustained by both of these materials before loss from the phosphate was in evidence.

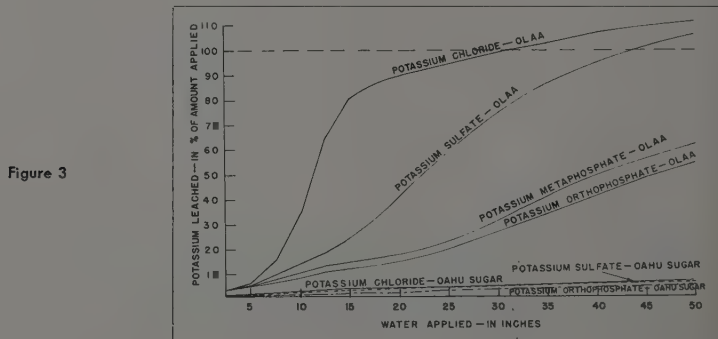
Losses of potassium from the three salts (and from potassium metaphosphate) in the case of a hydrol humic latosol at Olaa are contrasted in Figure 3 with corresponding losses from a low humic latosol at Oahu Sugar Co. With the latter soil, it is apparent that the form of potassium is of no consequence so far as leaching is concerned.

Early study had suggested that inability to retain potassium chloride and to increasingly retain the other salts of potassium mentioned was a property of soils of the high-rainfall areas. More recent work, however, has shown that such retention is primarily a question of degree of base saturation rather than of soil type.

Increasing the base status of unsaturated soils has markedly improved their retentive capacities with regard to potassium chloride, and thereby relatively decreased it with respect to the sulfate and phosphate. Conversely, soils capable of strongly retaining all three forms have been desaturated to the point where they exhibit, with respect to potassium retention, the properties of soils of naturally-occurring low base saturation.

### Field Tests

Field experiments in Hawaii have not shown potassium sulfate to be superior to the chloride for the production of sugar. Since, however, the differential susceptibilities of the two salts to loss by leaching has only recently come to light,



none of these tests was conducted in such a manner as to measure specifically the utilization of potassium from the standpoint of its retention by the soil. The outcome of such tests in the field might well be expected to reflect the vagaries of the weather—how much rain fell between the time potash was applied and the time the bulk of it had become immune to leaching through absorption by the crop.

### Recovery

For crops in general, recovery of potassium appears to be intermediate between that for phosphorus and that for nitrogen. A range of values of from 40 to 50 per cent seems to have been generally accepted. Calculation from the results of Stewart's study at Oahu Sugar Co. (11) gave a figure of 45 per cent.

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## DISCUSSION

**H. F. Clements:** Arthur, I assume that all of these leaching tests are done in the laboratory. Is that correct?

**A. S. Ayres:** Yes.

**H. F. Clements:** Why couldn't we have somebody from the Station dig a tunnel under some of our Hilo fields and really study leaching under natural conditions with the roots of the plants there? I wonder how different our whole picture would be if we were to do that. Wouldn't that be feasible?

**A. S. Ayres:** I don't know whether it would be feasible, but I think that such a study would mean a great deal more than these do. These, of course, indicate what can happen in the absence of plants which play a big role. We did take the precaution of keeping these soils moist—we didn't permit them to dry and, of course, drying changes these soils tremendously. But I agree with you completely. If we could do that, the data would mean very much more.

**H. F. Clements:** As far as feasibility is concerned, I think I could work on some of the people over there to let you dig that tunnel, and even to dig it for you if you can collect the leachates.

**L. D. Bayer:** You know, I've been interested in that too, Harry, in putting a lysimeter over there to get the information of just what does come down under natural conditions, because there is no question about it. When you've got a root system, you're going to have a different picture than what you have here.

**W. W. G. Moir:** We already had that on Oahu Sugar Company and Kekaha—the lysimeters installed in fertilizer tests for this information.

**L. D. Bayer:** What did that show? I don't remember that.

**L. Kerns:** We put tile drains under the line, and then caught the leachate and analyzed it and it came about six per cent, very close to the laboratory figures.

**H. F. Clements:** Now, wait a minute. Some of that was 110 per cent.

**L. D. Bayer:** But that was Oahu soils, Harry. George Ewart, did you have some lysimeter work over at Kekaha?

**G. Y. Ewart:** I don't remember the data.

**L. D. Bayer:** Of course, you two fellows are working with soils where, according to what the laboratory tests show, you wouldn't expect too much leaching from potassium chloride. You have a soil that's practically completely 100 per cent saturated with bases and not completely 100 per cent saturated with hydrogen like the Hilo Coast soils. You would have a difference in the amount of leaching that takes place in the Hilo Coast soils compared with yours. I think the data that Arthur presented here with respect to some of the things he has been doing with aqua ammonia are quite interesting, and I am sure those of you who are using aqua ammonia were glad to see some of the information that they have there. The only comment I have in regard to leaching is that when I first went to North Carolina with those sandy soils, it appeared that sandy soils would give you a tremendous amount of leaching because they had no base exchange capacity whatsoever. The thing that really surprised me when we got into the thing—because I wouldn't believe what they said when I got down there, they had to get some data to convince me—was that leaching was not nearly as bad as I had anticipated on the basis of the character of the sandy nature of the soil. Of course, these studies are done when they've got a crop growing. Apparently, as I understand it, when you've got an active plant root, it gets ahold of everything there as it goes by rather rapidly.

# THE APPLICATION OF SOLID FERTILIZERS BY HAND AND MACHINE

ORLANDO H. LYMAN\*

This discussion will deal almost entirely with the unirrigated plantations on the island of Hawaii. The general trend on this island is toward mechanical application of solid fertilizer. However, difficult terrain and unfavorable weather make it necessary to cover some of the area by hand either part or all of the time. High-clearance tractors are permitting relatively large cane to be fertilized by machine when the above limiting factors allow (Figure 1). In general, mechanical application is preferred by most plantations, since it results in more even distribution.

In plant cane, practically all of the phosphate, which is of quite substantial volume, goes on with the seed at planting, along with a moderate application of nitrogen. The practice of applying potash only after the cane is well started is being adopted by a number of plantations. Nitrogen and potash fertilizers are applied in subsequent split applications.

Since substantial per-acre volumes of fertilizer material are applied in the first dose and much smaller amounts in the later applications, a minor application problem has arisen. The heavy machinery needed to carry sufficient loads for planting are not needed for the later applications. Many plantations have continued with hand application at planting and developed machinery for the less bulky applications later in the crop.

Figure 1



\* Senior Island Representative, Island of Hawaii, Experiment Station, H.S.P.A.

## HAND APPLICATION OF FERTILIZER

The average application made by a man throwing fertilizer at the rate of five to six bags per acre is in the neighborhood of 25 to 30 bags per day. With infield transportation, usually mules, this brings the cost of application to a fairly sizeable per-acre figure. Throwing two lines at a time brings the cost down but decreases the refinement in placement. The use of a pipe attached to a bag aids greatly in placing the fertilizer in the line and speeds up the rate of application as well (Figure 2). In windy areas, this is a tremendous aid. In this connection, the mechanical qualities of the fertilizer mix are an ever-pressing problem, but with the use of granular muriate of potash, caking of mixed fertilizer has been greatly reduced.

## MACHINE APPLICATION OF FERTILIZER

Equipment for mechanical application of fertilizer has gone through many changes over the years. Today, the E-Z Flow equipment has been modified with respect to size and attachments and is proving very useful for both surface and subsurface applications.

Fortunately, the E-Z Flow, which is adaptable to both large and moderate applications, is not too expensive. Fertilizer flow is regulated with reasonable accuracy. As it is adaptable to numerous types of power devices, it has come into general use over the island. Its chief weakness lies in the susceptibility to corrosion of iron parts, but as the cost of replacement is not excessive, it has found favor in the industry over most of the other types.

As to future developments, bulk handling of fertilizer direct from the fertilizer plant to the distributors is a very possible course of cost reduction. Trials are now under way and bulk handling of fertilizer may find a place in the sugar industry in the not too distant future.



Figure 2

## AERIAL FERTILIZING

A. J. WATT, JR.\*

The title "Aerial Fertilizing" attaches a glamorous significance to an ordinary though important plantation operation. The old-timers who thought that nothing was better for cane than tankage and stable manure, would no doubt cast a dubious eye at today's new-fangled methods. Aerial fertilizing is the application of fertilizers in either solid or pellet form by an airplane flying at low altitude over a cane field.

Fertilizing by airplane seems to be especially suited to the unirrigated plantations of Hawaii. The Brewer plantations on the island of Hawaii are fertilizing extensively by airplane, and Olaa has adopted this method for the application of the greater portion of its fertilizer.

The first field-scale test at Olaa was made in April 1953, when a portion of a field received 50 pounds of N and 75 pounds of  $K_2O$  per acre by airplane. This mixture, GM #1, was made up of pelletized urea and granulated muriate of potash and contained 21 per cent N and 32 per cent  $K_2O$ . The fertilizer was applied at the rate of 235 pounds per acre. The results of this and other field tests were so encouraging that Olaa developed a new fertilizer schedule to make greater use of the airplane. Fields which received plant food at the age of 10 to 12 months responded by greening up quickly and by remaining greener than the checks for several months. Crop log indices remained at a higher level in the treated areas than in the checks over a considerable period.

Olaa has a contract with Murrayair, Ltd. to furnish an airplane, a loader, a pilot, and two crewmen. Olaa furnishes a foreman and two flagmen. Olaa also maintains two airstrips which are so situated that the maximum round trip does not exceed 15 minutes. Two-way radio contact is maintained between Murrayair's pickup at the airstrip and the foreman's pickup in the field. The pilot and the plantation foreman plan jointly such details as direction of flight over a field and location of flagmen. They also check with each other on effects of wind velocity on the distribution of the fertilizer. The two Murrayair crewmen load the high lift with fertilizer, which is then transferred to the hopper on the airplane (Figure 1). A company flagman is stationed at each end of a field and the plane flies in a straight line over each flag. After each pass of the plane, the flagmen move 30 feet down the field. These moves are repeated until the field has been covered. The plane carries 10 to 12 100-pound bags of fertilizer and can cover 100 or more acres per day.

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\* Cultivation Superintendent, Olaa Sugar Company, Ltd.

## FERTILIZER SCHEDULE AT OLAA SUGAR COMPANY

The fertilizer schedule at Olaa calls for six applications, the first two by tractor, the last four by airplane. Fields are about four months old when the first air application of 45 pounds of N and 75 pounds of  $K_2O$  goes on. Intervals between applications are about eight weeks. The last round goes on at 10 to 12 months. Some plantations have fertilized cane 14 months old. Olaa now applies 100 pounds N by tractor and 180 pounds by airplane. We expect to apply somewhat in excess of 3,000,000 pounds of fertilizer by airplane during 1954.

### PROBLEMS IN AERIAL FERTILIZATION

In case we have painted too rosy a picture of aerial fertilization, we might mention some of the problems which are still present. Rain is a problem in the wet districts and may cause a delay in schedule. The pilot flies in an open cockpit, and if it is raining, he cannot see. Wind is another problem and may be the cause of "streaking". Wind blowing across the path of flight at a velocity of 12 to 15 miles per hour will blow most of the pellets downwind, so that the center of the swath will move some 12 to 15 feet to one side. Gusty winds are most troublesome, and if flying is continued during gusty weather or when the velocity is around 15 miles per hour, yellow streaks can be expected to appear. However, streaks are easily eliminated by spot fertilizing with the plane. At Olaa, the first and third applications are flown in one direction and the second and fourth in the opposite direction, thus making for better distribution.

In spite of these difficulties, we feel that the airplane provides an excellent method of applying fertilizer, especially on the unirrigated plantations. It is the only method whereby fields over six or seven months of age can be fertilized. The new cane varieties are fast growers and close in early. Fertilizer can be applied by air up to any age desired. It is felt that if the period of fertilization can be extended, greater yields will result. At Olaa, where the terrain is uneven and rocky, distribution of fertilizer by air represents an improvement over the method of hand application.

Use of the airplane is advantageous in spot fertilizing, since this job can be done more effectively and cheaply by air than by hand. In fact, closed-in fields cannot be spot fertilized in any other way.



Figure 1

## THE APPLICATION OF SOLID FERTILIZERS IN IRRIGATION WATER

ROBERT CUSHNIE\*

Hand application of nitrogen and potash was discontinued at Ewa Plantation at the end of 1952. Since that time, all nitrogen and potash fertilizer materials have been applied in irrigation water.

Although some anhydrous ammonia was used in 1953, most of the nitrogen applied in that year was in the form of sulfate of ammonia. During 1953, a total of 2346 tons of sulfate of ammonia and 1315 tons of muriate of potash were applied in water to an area of 23,253 acres, which is equivalent to covering the entire plantation about two and a half times.

Most of the nitrogen applied in 1954 has been in the form of aqua ammonia, sulfate of ammonia being employed only in areas inaccessible to ammonia tanks. Potash has continued to be applied as the muriate. The totals, to the end of September 1954, were 81 tons of sulfate of ammonia and 890 tons of muriate of potash applied in water to an area of 8445 acres.

The equipment used for the application of solid fertilizers in water is very simple. It consists of a redwood platform, 88 inches by 24 inches, long enough to be placed across any supply ditch, with a constant-head box, measuring 24 inches by 36 inches by 8 inches, to maintain an even flow of the solution, and two 50-gallon open-top steel drums. The drums, in which the fertilizer material is dissolved, are set up, one on either end of the platform. Perforations of various sizes near the bottom of the drums, together with wooden plugs, regulate the flow. The drums discharge into the constant-head box, which is in the center of the platform directly over the ditch. The constant-head box also has perforations, which permit discharge into the ditch, wooden plugs regulating the rate of flow (Figures 1 & 2).

### PROCEDURE

The irrigation foreman, knowing the dosage in terms of bags of fertilizer per acre, which he gets from his fertilizer schedule, and knowing the rate of irrigation in terms of acres per hour, calculates the number of minutes required for the discharge of a drum of solution. With sulfate of ammonia, two 100-pound bags are usually dissolved in 50 gallons of water; but as muriate of potash is less soluble, only one 100-pound bag is dissolved in 50 gallons. For an application of three bags of muriate per acre, at the irrigation rate of one acre per hour, one drum of solution must be emptied every 20 minutes.

\* General Field Superintendent, Ewa Plantation Co.

Every station has an attendant whose job it is to fill the drums with water from the ditch, by means of a bucket, to dump in the fertilizer and stir it until it is dissolved, and to regulate the flow from the drum so that it is emptied in the required time. As the depth of the solution in the drum decreases, he removes some plugs in order to keep the level of the solution in the constant-head box always at the same point. Usually, he is busy making up the solution in one drum while the other one is being emptied. He occasionally stops to check and adjust the flow from the other one. The irrigation foreman tells him about any changes in the rate of irrigation which would require a change in the discharge time of the fertilizer solution. Needless to say, it requires considerable skill and experience on the part of the attendant to maintain the flow at the required rate.

This method of applying solid fertilizers may fall a little short of the accuracy obtained in metering out applications of anhydrous or aqueous ammonia, and it has the further disadvantage of requiring an attendant, but it remains a simple and practical method, requiring only inexpensive equipment.



Figure 1



Figure 2

## LIQUID FERTILIZERS AT OAHU SUGAR COMPANY

HANS HANSEN\*

For many years it has been the practice at Oahu Sugar Company to apply fertilizer as a dry mix by hand or machine, or to mix the fertilizer with water in barrels in the field and apply the resulting solution in the irrigation water. Because it takes less labor to apply fertilizer in irrigation water, Oahu Sugar began applying the greater part of its fertilizer by this method about 1946. The barrel method consists in putting the nitrogen, potash, and sometimes phosphate, into solution and applying an aqueous fertilizer from the barrels.

The materials applied were ammonium sulfate, ammonium nitrate, sodium nitrate, muriate of potash, and ammophos "B".

A study of the labor required to apply fertilizer by barrels at Oahu Sugar showed that during the peaks of the fertilizer season in April and in August, as many as 38 men per day were required to operate barrels, and that the average number of men per day was 18 for the year. Further study showed that substantial savings in manpower could be realized if a pre-mixed aqueous form of nitrogen and potash could be delivered directly into the irrigation water.

During 1950 and 1951, experiments testing anhydrous ammonia as a source of nitrogen were installed. No significant differences in yield were found between forms of nitrogen. In 1953, it appeared that the cheapest form of nitrogen that could be delivered to Oahu Sugar was aqueous ammonia containing 1.54 pounds of nitrogen per gallon. It was, therefore, decided to use aqueous ammonia, starting in 1954.

In order to realize greater savings in manpower, it was decided at the same time that we should apply our potash as aqueous potash through dissolving muriate of potash in water, each gallon of which would carry 1.5 pounds of  $K_2O$ .

In order to accomplish this, a mixing plant and storage facilities for aqueous potash, storage facilities for aqueous ammonia, delivery trucks and field storage facilities, were obtained.

Oahu Sugar Company's aqueous fertilizer facilities are as follows: a 100,000-gallon storage tank for aqueous ammonia; and a 5000-gallon mixing tank and a 55,000-gallon storage tank for muriate of potash. Three 2000-gallon delivery trucks are used for delivery to field storage (Figure 1). Field storage consists of fifty 750-gallon tanks on wheels which are moved by the irrigation overseers to any required spot (Figure 2).

Delivery of aqueous ammonia ranges from 8000 to 14,000 gallons per day, and aqueous muriate about the same. To run this operation requires half a day's work on the part of a supervisor, one man who receives aqueous ammonia from

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\* Assistant Manager, Oahu Sugar Company, Ltd.

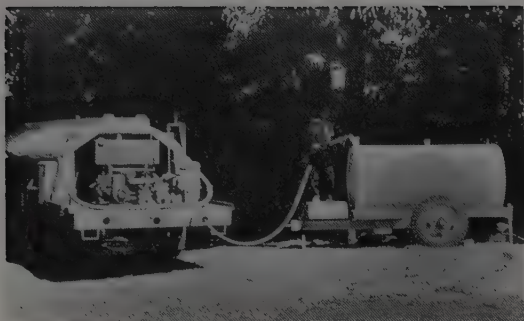


Figure 1



Figure 2

the supplier and who mixes and issues aqueous potash muriate, plus three truck drivers, or a total of four men and a supervisor, who has additional duties.

The use of aqueous ammonia has entailed no problems, but muriate has posed a serious one—corrosion. In order to inhibit corrosion, one pound of HSPA inhibitor is added to each 200 gallons of aqua muriate, but it is not entirely successful. Corrosion is not too important in the mixing and storage plant. It is important in the delivery and field storage tanks, and if we were to start again we would use stainless steel tanks for these jobs.

A further problem in aqueous muriate is the foreign matter—sand, cinders, pieces of wood shavings and jute bags, and a substance which takes several days to settle out and which resembles a clay. It is hoped ultimately to go into bulk muriate in place of bagged material, and if a sufficient number of plantations became interested, a cleaner form could probably be obtained at a lower cost.

The facilities, problems, and the savings have been described, and now I would like to describe very briefly the manner in which we deliver and control the flow of the fertilizer solutions into the irrigation stream.

A constant flow or constant head device is an integral part of the field storage tanks. Having a constant head, we are able to attach to the tank discharge a metering device which measures with great accuracy the rate of flow of aqueous fertilizer into the irrigation stream.

As stated previously, aqueous fertilizer is not new at Oahu Sugar Company, but the delivery of a pre-mixed solution is. Once the delivery and application of

aqueous fertilizer were arranged, the next problem was to obtain uniform distribution of fertilizer down the length of the furrow.

Preliminary investigation with nitrogen indicated that: (1) the pattern of distribution of nitrogen down the furrow is no better than the pattern of penetration of irrigation water; if your irrigation is poor, so will be the distribution of nitrogen; (2) regardless of position down the furrow, from 70 per cent to 80 per cent of the applied nitrogen at any one location was held in the top three inches of soil; 10 per cent to 20 per cent was found in the second three inches; around 10 per cent in the third three inches, and from 0-5 per cent was found below the fourth.

Studies were initiated to determine whether applications with aqueous ammonia were as satisfactory as with sulfate of ammonia. The results of these studies showed the distribution of nitrogen from sulfate of ammonia is substantially the same as that from aqueous ammonia.

No work has yet been done on the distribution of potash.

Oahu Sugar Company is well satisfied with the results of the conversion to aqueous fertilizer, so much so that now all fertilizer is applied in the aqueous form, except for the first application in plant cane where a dry mix is applied with the seed.



# THE APPLICATION OF AQUA AMMONIA WITH MECHANICAL EQUIPMENT AT KOHALA

A. C. STEARNS\*

## INTRODUCTION

While not new to continental United States, the recent development of aqua ammonia as a source of low cost nitrogen has had a stimulating effect on our agriculturists and engineers alike, in meeting the problems associated with the application of this form of plant food.

It is probably safe to assume that all plantations have re-evaluated their nitrogen fertilizer practices as the result of the introduction of aqua ammonia to the Hawaiian sugar industry.

Because of the cost reduction aspects of this new form of nitrogen, Kohala, in January 1954, began attempting to solve the operating problems affecting the use of aqua ammonia on unirrigated fields. This report deals with the methods used in applying nitrogen mechanically under these conditions.

## NITROGEN POLICY FOR UNIRRIGATED FIELDS

To set the stage for a discussion of the methods used, a statement should be made regarding the basic nitrogen fertilization policy on unirrigated lands at Kohala.

For ratoons, this policy calls for two applications of 50 gallons (75 lbs. N) each. The first application is made at the time of ratooning and the second application just prior to the time the size of the cane limits the passage of the high clearance tractor through the field. Placement of material in both applications is in the middle of the inter-row which is 4.25 feet in width. The first application is placed at an approximate depth of six inches and the second application at about two to three inches.

Supplemental field requirements for nitrogen in areas where high clearance machines cannot operate are met with hand applications of sulphate of ammonia, as in the past, or by airplane applications of urea.

To meet the requirements of this policy, Frank Gomes and John Mellen,\*\* engineers at Kohala, developed tractive equipment emphasizing simplicity of design and accuracy of application.

Equipment for our planting machine has not been completed, and hence the first application on unirrigated plant fields is not covered in this discussion. We

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plan to have such equipment, but we have lacked time to make the conversions. We have applied second applications of aqua ammonia on limited acreages of unirrigated plant fields with the same equipment used on ratoons. Although there has not been sufficient time to observe the effectiveness of the method, appearance of the fields and leaf nitrogen levels are encouraging.

## METHODS OF STORAGE AND DISTRIBUTION

Kohala's aqua ammonia storage system consists of a plantation tank which holds 28,000 gallons. This represents a two weeks' supply. Aqua ammonia is delivered to Kohala from Hilo by tank trucks.

Through a bulk loading station, aqua ammonia is transferred by gravity to truck-mounted tanks for local distribution. The distribution equipment consists of one 2000-gallon tank and two 750-gallon tanks. The latter are for use on all-wheel-drive truck units for rough mauka fields under adverse weather conditions. Each unit has its own 100 GPM transfer pump, driven by a gasoline engine.

Fourteen field tank trailers, each with a capacity of 750 gallons, can be used to store aqua ammonia at the field edge in unirrigated areas. In irrigated areas, the same tank trailers may be used to meter the aqua ammonia into the irrigation water.

The tractor units move from the point of application in the field to the trailer on the road, and the operator handles the loading of the tractor from the trailer. The trailer is moved occasionally so that the distance between tractor and trailer does not become too great.

## TYPE OF EQUIPMENT USED

The following types of tractor equipment are used: Caterpillar D-6, 3 units, and one Farmall M V High Clearance tractor (Figures 1 and 2). Aqua ammonia is applied through the use of ground-driven positive displacement pumps. A pump, mounted over each track for each subsoil standard, meters the ammonia. Each pump is driven by means of a clutch-operated, chain-drive assembly, from a track-carrier roller-star wheel unit. The pumps take suction from 75-gallon tanks which are also mounted over each track. An air surge chamber, suction line filter, relief valve, quick-closing valve, and an orifice plate assembly complete the metering equipment.

A clutch-operated transfer pump, driven by the rear power take-off, is used to fill the two 75-gallon track tanks. This transfer pump takes its suction from the field tank trailers.

On the Farmall unit, three positive displacement pumps are mounted on the rear of the tractor, instead of two, as on the Caterpillar D-6. Unique in this assembly is a pump for each point of injection. A single, clutch-operated jack shaft, driven by a ground-drive assembly mounted on the right rear wheel of the tractor, drives the pumps. These pumps take suction from a common header which is fed by two 75-gallon tanks mounted on each side of the tractor. Each pump delivers aqua ammonia to a single ground knife located midway between the cane rows. The pumps and tanks are the same on both types of tractor.

Through the end of August of this year, aqua ammonia applications were made on 2215 unirrigated acres. The scheduled application called for 50 gallons of aqua ammonia per acre. Actual applications have averaged 51.5 gallons per acre. This



Figure 1. Caterpillar D6 subsoil, two-line, aqua ammonia tractor at Kohala Sugar Company.



Figure 2. Farmall MV high-clearance, three-line, aqua ammonia tractor at Kohala Sugar Company.

indicates the accuracy of calibration which is controlled by sprocket size. Our program for the use of aqua ammonia is expanding. In 1954, 57 per cent of the nitrogen applied will be from this material. Next year, it may reach as high as 75 per cent.

The combination subsoiler-aqua-ammonia unit that is used for the first application of nitrogen at time of ratooning averages approximately 11.3 acres per eight-hour day. The Farmall High Clearance tractor which is used for second applications averaged 16 acres per eight-hour day.

Following are the specifications of the metering and transfer pumps:

**Metering Pump**

Type	—Duplex Positive Displacement
Model	—John Bean #64
Capacity	—4 GPM @ 400 p.s.i.
The pump has stainless steel valves and the unit is supplied with porcelain-lined pump cylinders	

**Transfer Pump (Field trailer to tractor)**

Type	—Modified Jacuzzi Centrifugal Pump
Model	—Jacuzzi—B7HA1½
Capacity	—60 GPM @ 20 feet of head

**Transfer Pump (Supply truck to field trailer)**

Type	—Modified Jacuzzi
Model	—Jacuzzi—Z15AH2
Capacity	—100 GPM @ 25 feet of head

## EFFECTIVENESS OF THE METHOD OF APPLICATION

The effectiveness of a new practice is always a matter of concern until field results have been established by adequate testing. We are testing for the first application the practice of applying aqua ammonia in the center of the inter-row as compared to applying dry forms of nitrogen on top of the stubble. Although it is recognized that more data are needed to permit a final evaluation, some preliminary data may be of interest.

Crop log data for leaf nitrogen have been compared for all fields started in 1952, 1953, and 1954. The August analyses were averaged for each year. In 1952, the per cent N was 2.24; in 1953, 2.26 per cent N; and in 1954, 2.48 per cent N. The average ages of canes for the periods compared were 4.3, 4.2, and 4.5, respectively. Practically all of the 1954 nitrogen was aqua as compared to dry forms used in previous years. The 1953 nitrogen was placed on the top of the stubble, while in 1952 it was placed in the subsoil in the center of the inter-row. The cane is still young and crop response will have to be watched as it becomes older.

In a limited number of block comparisons, there was only one instance where the aqua treatment showed a visible deficiency compared to blocks that received urea on top of the stubble. In this case, the per cent leaf nitrogen was 2.09 in the aqua area and 2.45 in the urea block. The cane was six months old at the time the samples were taken. Since there was only one such case, we have wondered if the proper amount of nitrogen was actually applied. Further comparisons are being installed to check the practice.

An aqua ammonia placement experiment was installed early in the summer in cooperation with the Experiment Station. In the first treatment, both the first and second applications of nitrogen were placed in the center of the inter-row. In the second, the nitrogen was placed on, or as close to, the ratoon stubble as the equipment would permit.

In the first treatment, the D-6 subsoiler unit made the first application. The Farmall unit applied the first application on the stubble. It should be pointed out that at the time of installation it was the consensus of those present that the soil knives were not going deep enough into the stubble. However, the damp soil apparently held the aqua ammonia, even though some must have been on the surface. There appears to be no measurable difference between the treatments at four months of age.

## OPERATING PROBLEMS

With any new piece of equipment and generally with new methods, some phase of the operation sometimes fails to measure up to original estimates. The following information is given for the benefit of those who can use it.

We have experienced no serious problem with the track-type subsoiling unit. It operated in a satisfactory manner from the first day it went into the field.

Our Farmall unit, however, has presented several problems, principally because the tool frames are too light and hence are easily damaged. Furthermore, the bouncing of the unit on the rubber tires creates a problem in maintaining a uniform depth of application. We have also found that the use of this unit is limited on steep slopes. In areas where the high clearance unit cannot be used effectively, approximately half of the second application of nitrogen has been applied by hand (sulphate of ammonia). Weeds, dead or alive, as well as soil

compaction, affect the penetration of the soil knives on the second application.

It is important for you to know that your storage tank should be properly vented. We were late in receiving our vacuum relief manhole cover, and checks indicated decreases in concentration of nitrogen from approximately 20 per cent to as low as 17 per cent. Installation of the cover prevented further loss. At times, we have measured a loss of 1 per cent in concentration between the storage tank and the field.

A real source of savings that has not been fully explored is that of reduced truck and labor time for transporting fertilizer to the field.

### PRELIMINARY RESULTS ENCOURAGING

After eight months' experience in the application of 114,052 gallons of aqua ammonia on unirrigated land, it appears that tractor equipment, simple in design but accurate in application, can effectively apply this fertilizer under Kohala conditions. Results to date have been encouraging. We are continuing to install tests to measure the effectiveness of placement.

In conclusion, it seems appropriate to emphasize the matter of safety in handling aqua ammonia. Properly designed equipment, protective devices where required, plus adequate training and a personal awareness of working safely, are needed. New methods and materials require new safety procedures. It is important!

## DISCUSSION

**Jack Larsen:** Mr. Cushnie, does Ewa anticipate using more aqua ammonia in the future?

**R. A. Cushnie:** I think we're using all the aqua ammonia that we feel is possible. The sulphate of ammonia that we are using at the present time will eventually be replaced by aqua as soon as we get our roads in. We are having a bit of a problem with our large tanks in some parts of the plantation, but once we get the roads licked, we will be 100 per cent aqua ammonia.

**Walter Naquin:** Bob, have you ever figured on using aqua potash mixed at a central station as Oahu Sugar is doing?

**R. A. Cushnie:** At the present time Warren Gibson of the Industrial Engineering staff is making a study on mixing potash at a central station, and taking it out. So far, we have not come to any conclusions, but I feel that it is probably something that we will be going into.

**H. F. Clements:** Is it true, Walter, that at Waialua your figures don't look as though you could gain by dissolving your potash at a central plant? What are the figures? Are there figures developed elsewhere that would bear on that point?

**Walter Naquin:** I can't give you the cost figures, but I can tell you that our industrial engineers have studied it, and we find that we have reached a breaking point in the use of our handling equipment. The load lugger is busy handling the aqua ammonia tank, and the investment in tanks for potash, the investment in a central mixing station, and the investment in another truck to haul these tanks out to the field and deposit them on the ground, aren't justified by the short period when we have a labor shortage. That is, if we had a labor shortage through the entire year on the plantation, our capital investment to accomplish this liquid potash would look a little different, but actually we figure our labor shortage generally in July, August and September. During the rest of the early and latter parts of the year, with rains and the rather short harvesting season, we have men available and actually, you might say, no other jobs to put them on. So that's one of the reasons we haven't gone into aqua potash.

**Philip Conrad:** Walter, in your study of the load lugger, what amount of money have you put into it?

**Walter Naquin:** The truck and load lugger cost \$15,000, delivered here in the Islands—around that figure; a 10-ton truck and lugger. The advantage, if you have one of those things, is that you don't have a whole lot of rubber out in the fields in the form of small trailers. You can set your tank right on the ground.

**R. P. Humbert:** I am sure Hans Hansen will have more to say about that particular topic in the next discussion.

**D. S. Judd:** Alister Watt mentioned that the airplane flew in one direction on the first and third applications, then the opposite direction in the others. Do you mean 180° or 90°?

**A. Watt:** That's 90°. We apply it one way the first and third, then we start crossing the second and fourth.

**D. S. Judd:** That would be only of limited application, depending on the field. With certain fields, it would be impossible to do that.

**A. Watt:** In most cases, you can come in on an angle of some kind which helps the distribution of the fertilizer.

**Herbert Gomes:** How do you manage with aerial fertilization to keep away from fertilizing the pali cane or planters' cane that is scattered out in between the plantation cane?

**A. Watt:** We have roads on all the boundaries so we are able to keep out of the planters' cane, although we do get some drift from the wind. That's about all, unless somebody makes a miscue.

**L. Thevenin:** What does the D6 cost fully equipped?

**A. Stearns:** It just happens that we have the guy here that built it, so I will ask Frank Gomes how much it cost.

**Frank Gomes:** The cost of installing the aqua equipment was approximately \$1600.

**H. F. Clements:** Why don't you put your E-Z Flow right on the same machine for your potash applications?

**A. Stearns:** I think the primary reason we haven't moved to a dual machine at this point is that we didn't want to complicate our effort in this direction and our engineers felt that we could do a better job on our aqua machine by confining it to a single operation. We could put it on, but we do have a fairly safe and effective method of putting our muriate on with the wide E-Z Flow pulled behind a Farmall. I think Orlando indicated that this covers 24 acres a day—somebody else had a little higher performance. That's the primary reason.

**H. F. Clements:** Actually, though with a D6, you have much more power there than you need for a job like that, haven't you?

**Frank Gomes:** That's a question that always comes up, Harry, and actually, with the relatively small tank that we have aboard the D6—we have a 150-gallon total capacity—we have to operate about 15 per cent of the time in low gear, but we're not taking it too easy on that D6 tractor.

**J. F. Morgan:** What is your rate of application with this subsoil type?

**A. Stearns:** 50 gallons per acre.

**Question:** Would you be a little more specific on your corrosion problem with your tanks?

**H. Hansen:** The corrosion problem is real. We have the tank built of mild steel and even with the inhibitor, especially over weekends, when we only have an empty tank, corrosion occurs. On Monday morning we have to be very careful that the orifice is not clogged up within an hour or so after we start going again. Also, our delivery tanks were bought for gasoline. They're very thin metal, and the corrosion there is also a real thing. We had some trouble there; we have strainers in our pumps, strainers in our meters, and the first thing we knew, within an hour or so, our strainers were all plugged up with rust.

**Question:** Did it make holes in the tanks?

**Hans Hansen:** Yes, in one. It was in the weld—not in the sheet metal itself.

**R. P. Humbert:** I might say I had occasion to visit American Potash & Chemical Company plant at Trona this past summer, and they have had a lot of experience in this corrosion problem with muriate of potash. They are working with potash solutions for agriculture on the West Coast. I have the benefit of their experience and their recommendations will be circulated to all plantations very shortly.

**Keith Tester:** First, I would like to say that I rather feel that our industrial engineers don't get together on some of these common problems. Ours definitely recommended that we stay out of aqueous potash because it was going to cost us money. Now, you must be saving money. How much do you save?

**H. Hansen:** I'd say the actual money you'd save in aqua potash—there is a question there. You may about break even on it. If you want to get the full savings, it was in manpower. As far as gallonage goes, we apply almost the same gallonage of aqua potash as we do of aqua ammonia, and with 18 men per day on the average, applying fertilizer in barrels, it would be almost nine men on each—the aqua potash and aqua ammonia—and that is a saving of nine men. We're keeping very accurate records this year, even though we didn't start off very well. We had a lot of problems to begin with. I don't think our industrial engineers always figure out all the various things that are going to happen to your system, and a lot of things did happen that we didn't expect. Therefore, I think that the indication is now that there will be a saving—a great saving—in aqua ammonia, but not a great deal in aqua potash.

**Keith Tester:** I was referring to aqua potash. Practically everyone realizes the savings in aqua ammonia.

**Hans Hansen:** You'll have to admit you're hauling a lot of water.

**Keith Tester:** I think there is a possibility of saving with aqua potash.

**Hans Hansen:** Even if you break even, you're doing better than you did before.

**Karl Berg:** I understand that Wailuku has been using aqua muriate quite successfully for two or three years. It might be interesting to ask them what they have done to overcome the corrosion problem.

**Stanley Tutton:** We have equipment that's been used for some period of time which is very well corroded, but not yet corroded through. Then there's the difficulty you mentioned of having the outlets plug up.

**Noel Hanson:** On the matter of corrosion, there are several plastics becoming available at the present time which I think we are going to have to bring in under test. I think that so far as Murrayair's use of fiberglass tank in their planes, Bill Stearns or someone else from Murrayair would care to comment on that. Fiberglass is now being used for coating materials, and I think that is a direction in which we might go in this matter of corrosion.

**Wm. Stearns:** As anyone that has been connected with our aerial applications is very well aware, we have quite a problem of corrosion. We haven't completely licked it; frankly, we're still a long way away from it, especially on our ground rigs. On the airplanes, we have installed a fiberglass hopper which holds approximately 1200 pounds, and so far, it is as good as the day it was installed.

**R. Q. Smith:** I believe, Roger, that Olokele had some experience. I know they had some rubber-lined tanks, and they had muriate in one of them. The orifice got plugged up. I believe it was caused by the coating they put on the inside of the rubber. I know we have thought of fiberglass-lined tanks for distribution of other corrosive materials such as ammonium nitrate.

**J. Cushnie:** We haven't used any muriate, just the aqueous ammonia. In our big tanks, we had one peel off a little bit on the top part of the tank. It wasn't serious.

**W. M. Moragne:** We have found that the roadside tanks, 1000-gallon mild steel tanks, do give us trouble with corrosion, but with us, it's a simple matter to make a few tanks out of stainless steel. I'm sure there would be no trouble whatsoever from then on.

**Hans Hansen:** Bill, do you have to use a special alloy of stainless steel?

**W. M. Moragne:** You've got me there, Hans. I think we use about what everybody uses. It isn't anything special. We've been using it right along. I think it's the same stainless steel that's used in sink tops.

**Hans Hansen:** I asked because when we had our stainless steel meters and pumps made, they insisted that it be a special alloy to be able to take corrosion.

**T. Thomas:** The type 316 stainless is one of the most highly recommended.

**Q. H. Yuen:** I'd like to ask Mr. Hansen, did he say he used one pound inhibitor for 50 gallons, or one pound in 100 gallons?

**Hans Hansen:** One pound to each 200 gallons.

**Q. H. Yuen:** On your corrosion, do you have trouble during the day, or only during week ends?  
**Hans Hansen:** Primarily the week ends.

**Q. H. Yuen:** I think you will find you'll have an improvement in inhibition of corrosion if you used one pound per 100 gallons, then during the weekend better clean and keep your storage tanks empty, fill them up with solution and put the whole two pounds of inhibitor to 100 gallons. Then you won't have any trouble with corrosion.

**Hans Hansen:** We already have a test running with that double amount.

**Q. H. Yuen:** Two pounds per 100 gallons. Fill your tank up—don't keep your tank empty. If you keep your tank empty, you'll have to wash the tank out.

**R. L. Luckhardt:** For several years, I was with a company that has handled nothing but corrosive liquids. Our experience was that there is nothing you could paint in a tank but what would some day disappoint you, and that rubber, or some plastics, or stainless steel were the only things you could use and not find it on the ground next Monday morning.

# NUTRITIONAL DEFICIENCY SYMPTOMS IN SUGAR CANE

R. P. HUMBERT AND J. P. MARTIN\*

The environment of the plant is made up of climatic factors and physical and chemical factors of the soil, and determines those agricultural crops which can be grown economically in a given region. Since the soil is the medium in which plants are grown, soil-plant relationships must be understood in order to secure maximum yields of any agricultural crop.

The growth of a plant is recognized by permanent changes in form which are usually accompanied by increases in size and weight. The rate of growth is determined by the environmental conditions, some of which can be modified beneficially while others cannot be changed. As a rule, most of the elements essential for plant growth occur in the soil in quantities sufficient to sustain natural vegetation. However, when economic crops are grown, it eventually becomes necessary to supply additional plant nutrients. The kind and amount to be supplied depend largely on the fertility of the soil and the nature and size of the crop.

This paper deals chiefly with the sugar cane plant and some of its nutritional deficiency symptoms. Cane plants making satisfactory growth exhibit good color and rate of leaf and stalk development. Plants not making satisfactory growth are stunted and frequently manifest symptoms of some nutrient deficiency. Excesses of one or more elements may, in some instances, result in symptoms of distress.

Subnormal growth combined with changes in leaf color and development of spots or streaks on the leaves are visible expressions of a nutritional deficiency. In recent years, color photography, combined with an adequate description of a particular deficiency, has made it easier to recognize deficiency symptoms and record them for use in other problem areas and for training purposes.

The deficiency symptoms of nitrogen, phosphorus, potassium, calcium, magnesium, manganese, iron and sulfur have been induced in nutrient solutions under controlled conditions and studied by various investigators at this Station. The results of these studies have proved very useful in recognizing similar symptoms on cane growing under field conditions. Deficiency symptoms of the following elements have been observed on cane plants in the field: nitrogen, phosphorus, potassium, iron, manganese and possibly, on plants growing in very acid soils, calcium and magnesium. Deficiency symptoms of sulfur have not been noted on cane in the field, but they were quite definite in nutrient solution studies. Ammonium sulfate and superphosphate used over the past 20 years have un-

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\* Respectively, Principal Agronomist and Principal Pathologist, Experiment Station, HSPA. The authors wish to acknowledge the assistance of T. A. Jones and H. H. Hagihara who completed the spectrochemical and chemical analyses of the samples.

doubtedly supplied adequate quantities of sulfur. Deficiencies of boron, zinc, copper, and molybdenum have been reported in other crops grown in Hawaii, and since copper and zinc deficiencies have been reported in cane in other sugar-producing areas, they were investigated in this study.

Some five methods are available for studying mineral requirements or deficiencies in plants. These are:

- 1) Chemical analysis of the plant.
- 2) Soil analysis.
- 3) Pot tests with the cane plant or with indicator plants.
- 4) Field tests.
- 5) Visual diagnosis.

The first four methods are evaluated in various papers of this seminar. The last method has played a major part in recognizing the presence of deficiencies. Foliar diagnosis of early signs of distress often results in the correction of the deficiency and in obtaining satisfactory yields of a marketable product. When the deficiency is not corrected in time, yields are reduced and the product is often inferior.

#### CHEMICAL COMPOSITION OF SUGAR CANE GROWN IN NUTRIENT-DEFICIENCY SOLUTIONS

Plant growth is often retarded by nutrient deficiencies before visual symptoms of distress have developed to the point where identification is possible. Analyses of sensitive plant tissues should help interpret what the plant is trying to tell us when it reduces its rate of growth. The objective of the recent deficiency series was to establish points of deficiency by harvesting and analyzing the various parts of the cane plant after definite deficiency symptoms had developed.

The four leading commercial varieties—32-8560, 37-1933, 38-2915 and 44-3098—were grown in complete nutrient solution and also in solutions lacking, respectively, nitrogen, phosphorus, potassium, calcium, magnesium, iron, manganese, boron, molybdenum, zinc, and copper. At harvest, the plants were divided into: (1) leaf blade—3, 4, 5, and 6 with midribs removed, (2) leaf sheath—3, 4, 5, and 6, (3) immature stalk, and (4) mature stalk. The mean values for the four varieties of the complete and deficiency series are presented in Table 1.

**TABLE 1. CHEMICAL ANALYSES OF DEFICIENCY SERIES**  
Mean Values for Varieties 32-8560, 37-1933, 38-2915 and 44-3098  
Results expressed as per cent of dry weight

	Blade	Sheath	Stalk Immature	Stalk Mature
Complete. . . .	1.30	.60	1.25	.37
minus N. . . .	.70	.32	.65	.19
Complete. . . .	.27	.24	.31	.32
minus P. . . .	.13	.09	.15	.05
Complete. . . .	1.90	2.40	4.45	1.30
minus K. . . .	1.00	.90	2.40	.14
Complete. . . .	.34	.18	.43	.08
minus Ca. . . .	.06	.01	0	.008
Complete. . . .	.092	.076	.110	.072
minus Mg. . . .	.021	.017	.042	.018
Complete. . . .	.0079	.0047	.0060	.0059
minus Fe. . . .	.0050	.0035	.0046	.0070
Complete. . . .	.0020	.0015	.0025	.0005
minus Mn. . . .	.0003	.0002	.0004	.0002

No clear-cut deficiency symptoms were observed with the plants in the minus boron, zinc, copper, and molybdenum series, even though some precautions against contamination were taken. The single-eye seed pieces were cut short and, after germination, were transplanted into sterilized quartz sand where they remained until they had reached a size adequate for the nutrition pots. Ion exchange water and reagent grade chemicals were used in these studies. Nevertheless, all four varieties secured enough of these trace elements from the seed and from impurities in the chemicals and water to develop without manifesting deficiency symptoms. The various parts of the plant were analyzed to give an indication of what the lower sufficiency levels might be. The results are presented in Table 2.

TABLE 2. SPECTROCHEMICAL ANALYSES OF LEAF BLADES  
OF DEFICIENCY SERIES WITH VARIETY 44-3098  
Results expressed as ppm

Nutrient Solution	Mo	Cu	Zn	B
Complete.....	3.4	10	33	
Minus Mo.....	<1			
Minus Cu.....		5		
Minus Zn.....			23	
Minus B.....				<1.8

## DESCRIPTION OF NUTRIENT DEFICIENCY SYMPTOMS

*Nitrogen Deficiency.* Plants deficient in nitrogen show a uniform yellowing of all leaves and a retardation of growth. Cane stalks are small in diameter and a premature drying and dying of the old leaves takes place. Roots attain a greater length but are smaller in diameter than those receiving an adequate supply of nitrogen.

Nitrogen occurs in the chlorophyll molecule. It also combines with carbohydrates to form proteins which play a major role in the synthesis of protoplasm. With an abundance of carbohydrates and nitrogenous compounds, growth may be rapid, which is desirable in the boom stage of sugar cane growth. When nitrogen is deficient, the leaves develop a yellowish color, growth is retarded, and sugar accumulates or builds up in the plant. As the plant approaches maturity, this condition is to be desired. Of the major elements essential for plant growth, nitrogen has the greatest effect on cane ripening and juice quality.

*Phosphorus Deficiency.* Cane plants inadequately supplied with phosphorus manifest a lack of tillering, which results in a thin stand of cane. The stalks of such plants are small in diameter with short internodes, and taper rapidly at the growing point. The leaves are narrow and are of a greenish-blue color in contrast with the wide, dark green leaves of normal plants. The older leaves exhibit drying and dying at the tips and margins. Root development is restricted.

Phosphorus helps to build proteins. It occurs in the nucleus in living cells and is thought to control most cell activities. It is essential for the cell division which accounts for stalk and root elongation or the growth of the plant.

*Potassium Deficiency.* Plants suffering from a lack of potassium show a depressed growth, a yellowing and spotting of the older leaves, and the development of slender stalks. The older leaves develop an orange-yellow color with numerous chlorotic spots which later become brown with necrotic centers. As the spots coalesce, general browning of the leaf results. A reddish discoloration which is confined to the epidermal cells develops on the upper surfaces of the midribs.

Later, the leaves begin to die back from the margins and tips. This condition of the leaves is sometimes referred to as "firing".

The young leaves of plants deficient in potassium are dark green in comparison with the older, yellowish leaves. Both young and old leaves appear to have developed from a common point—a characteristic of a cane plant that is not growing.

Potassium within the plant is mobile and moves from the older to the younger parts. Hence, the youngest leaves are the last to manifest deficiency symptoms. This element is essential for cell division, carbon assimilation, translocation of sugars, starch formation, the entry of water into the plant, and normal root development.

*Calcium Deficiency.* The first symptoms of calcium deficiency on the leaves are minute chlorotic spots with dead centers that later turn to a dark reddish-brown. The intensity of the spotting increases with the age of the leaves. Growth is retarded and the plants become weak, the rind becomes soft. Eventually, growth is completely stopped, and the plants die.

Calcium is essential for the formation of calcium pectate which aids in cell wall development and the middle lamella which binds the cells together. Certain calcium salts are thought to act as antitoxic agents by forming semi-permeable membranes, thus protecting the protoplasm from contact with toxic elements. High magnesium concentrations are made nontoxic by the addition of calcium. Gypsum or calcium sulphate is often applied to alkali soils to counteract the harmful effects from excesses of magnesium or sodium salts. Many investigators consider calcium one of the more important elements in plant nutrition.

*Magnesium Deficiency.* The symptoms of magnesium deficiency are in some respects quite similar to those of potassium and calcium deficiencies. The young leaves are light green while the old leaves turn yellowish-green, these changes becoming more pronounced as the deficiency continues. Small chlorotic spots which later turn to dark brown develop on the older leaves. These leaf markings, when numerous, coalesce and give the older leaves a rusty appearance.

In advanced cases of magnesium deficiency, the leaves are chlorotic and severely spotted; the stalks are small in diameter with shortened internodes, and show an internal browning. Root systems are restricted in growth.

Magnesium is a constituent of chlorophyll, and a deficiency of this element results in a chlorotic leaf condition followed by depressed growth.

*Iron Deficiency.* The first symptoms of iron deficiency appear as a general paling of the youngest leaves followed by the development of alternating green and chlorotic stripes extending the full length of the leaves. The normal green color between the small vascular bundles first disappears, leaving the green around the large bundles only, thus giving the striped effect. If the deficiency continues, the striping becomes less conspicuous and the leaves appear more uniformly chlorotic. During these changes in young leaves, older leaves retain their dark-green color.

In acute cases of iron deficiency, marked contrasts often occur in the leaves wherein the youngest may be entirely white, the intermediates partially green, and the oldest subnormal green. If iron is not supplied, the plants die.

Plants deficient in iron are depressed in growth and exhibit a restricted root system. Limited secondary root development results in a markedly stubby appearance.

Limestone and ratoon chlorosis are two types of iron deficiency frequently observed on cane under field conditions. Many of the red soils contain high amounts of both iron and manganese; and as the result of the unbalanced ratio between these two elements, insufficient quantities of iron are available for normal growth.

In water-culture studies, symptoms of acute iron deficiency developed on cane plants when iron was maintained at 5 ppm and manganese at 10 ppm or more. Normal growth resulted when the iron-manganese ratio was 15:1 or greater, but with an iron-manganese ratio of 1:1 or less, iron deficiency, or manganese toxicity, developed.

Iron, although not a component part of the chlorophyll molecule, is essential for its formation so that without an adequate supply of iron, plants soon become chlorotic.

*Manganese Deficiency.* The early symptoms of manganese deficiency are characterized by a fading of the normal green color between the leaf bundles followed by the development of definite, pale, yellowish-green to white longitudinal stripes. The stripes are confined to the middle and tips of the leaves and seldom extend the full length of the leaves as they do in cases of iron deficiency. These differences aid greatly in differentiating the deficiency symptoms of manganese from those of iron. Where manganese deficiency is acute, the chlorotic stripes become white. Reddish-brown areas of dead tissue also appear, which later cause continuous stripes and split the leaf longitudinally.

Manganese deficiency, or Pahala blight as it was formerly called, was at one time quite severe on several of the Hawaii plantations. Applications of manganese incorporated into the fertilizer have given excellent control of this deficiency.

The relationship of manganese to iron in cane growth is discussed under the heading of iron deficiency. Leaf symptoms of manganese toxicity, induced in water cultures, were similar in every respect to those of iron deficiency.

Manganese is thought to aid in certain oxidation processes which take place within the plant. It is also considered of special importance in the development of meristematic tissues.

*Boron Deficiency.* When cane plants are deprived of boron, minute, elongated, watery spots soon develop on the young leaves. These markings are parallel to the vascular bundles and result in a definite striping. The leaf lesions soon enlarge and manifest sunken areas or depressions in their centers. Frequently on the lower leaf surface, minute, elongated, gall-like bodies develop. In mature lesions, the leaf tissue cracks. Young leaves become narrow, very much shortened, chlorotic, and badly distorted. Growth is greatly retarded and stalks remain small in diameter. If boron is not returned to the culture solution, the plants finally die. Internal, brownish streaks frequently develop at and slightly below the growing point. The advanced leaf and stalk symptoms are in many respects similar to those of pokkah boeng disease of sugar cane.

Boron is essential for normal development of those parts capable of making further growth. Boron deficiency in cane and in other plants is first recognized by the distortion and off-color appearance of the new growth.

*Sulfur Deficiency.* The early symptoms of sulfur deficiency suggest those of nitrogen deficiency in that the young leaves develop a uniform light yellowish-green color. Later, the young as well as the old leaves assume a faint purplish tinge

which indicates an accumulation of carbohydrates and the formation of anthocyanin.

The leaves become narrow and fail to attain their full length. Stalk diameter is reduced, elongation is slowed down, and the plants are generally stunted. As previously mentioned, no symptoms of sulfur deficiency have been observed on field cane.

Sulfur is a constituent of certain proteins which enter into the formation of the protoplasm of plant cells. A deficiency of sulfur would, therefore, be expected to retard growth.

## PLANT NUTRITION IN RELATION TO CANE DISEASES

The nutritional status of the cane plant has a marked influence on the incidence of several major diseases of this crop.

Leaf freckle is most severe on canes which are growing in soils of low fertility and which are exposed to low temperatures and high rainfall. In soil exchange tests, the absence of freckle on 44-3098, when grown in fertile makai soil under mauka conditions, clearly demonstrated a direct correlation between the low degree of freckle and high soil fertility plus good soil tilth.

The severity of *Pythium* root rot on susceptible varieties increases when nitrogen is applied in excess of the plant's requirements. It has been shown that a phosphate deficiency increases the amount of root rot in D1135 and certain other varieties. In 1933, nutrient solution studies showed that a deficiency of any one of the following elements—calcium, iron, magnesium, manganese, phosphorus, potassium and sulfur—favored the development of root rot in the commercial varieties. In the same study, however, it was demonstrated that a deficiency of nitrogen greatly reduced the severity of the disease.

Eye spot disease has always appeared in its most aggravated forms in makai areas of high soil fertility and in areas receiving high applications of nitrogenous fertilizers. Susceptible varieties, making slow growth as the result of lower applications of nitrogen, were less affected than the same varieties making a more rapid and succulent growth in the presence of ample nitrogen.

Chlorotic streak disease, from many field observations and nutrient studies, appears to be most severe in cane grown in media deficient in potassium. This is true on Hawaii along the Hilo Coast. The disease is also prevalent in areas subject to heavy rainfall or to poor drainage.

Brown stripe disease is most pronounced on canes growing in soils of low fertility. A marked control of the disease resulted when potash and particularly phosphate above the normal field practice were applied to areas where this leaf disease was prevalent.

Leaf scald in Hawaii and elsewhere has been shown to be associated with environmental conditions, the severity of the disease increasing when growth is retarded as the result of low fertility or drought. It also increases as the cane plant approaches maturity.

Ratoon stunting disease has less effect on canes making a normal growth than on those making a subnormal growth. Losses from the disease are greatest where canes are growing in soils deficient in one or more of the elements essential for growth or in soils deficient in moisture.

## SUMMARY

1. Deficiency symptoms of nitrogen, phosphorus, potassium, calcium, magnesium, iron, manganese and boron were developed in nutrient solution for the commercial varieties 32-8560, 37-1933, 38-2915 and 44-3098.

2. Chemical analyses of leaf blade, leaf sheath, immature stalk and mature stalk samples are presented to show composition at deficiency levels of nutrition. Comparison of the analyses of normal and subnormal field samples with these data, should give leads to maintain a satisfactory nutrient balance.

3. The effects of nutrition on the incidence of major diseases of sugar cane in Hawaii are discussed.

## DISCUSSION

**R. Toyofuku:** We harvested field 19 Lihue, and when we plowed that field, an old supply ditch that had been there for many, many years was filled with mill mud and also with filter cake. Along that big supply ditch there was also a rather cutdown roadway, and that road was also filled in with mill mud and filter cake. When that field was planted to 2708 and the cane was about four months of age, we noticed in particular the differences in color and growth of the three sections, the fields on both sides of these filled-in areas, the supply ditch and the roadway. It seemed to me that the field was perhaps a little bit subnormal, it wasn't doing as well as it might under the conditions, but the filled-in area, the supply ditch that was filled in, was definitely retarded in growth and was off-color. We feel there that it might have been unbalanced in the C/N ratio. I think that there was an N deficiency, but the field road that was filled in was also given some mill mud and so it might have been unbalanced, too. But somehow or other, it had outstanding growth and color. The cane in the roadway was superior to that in the field. I wonder whether it was nutrition or something else that might have caused the better growth in the roadway in spite of the added mill mud.

**R. P. Humbert:** Ronald, your observations on the filling in of areas and depressions, ravines, and that sort of thing, are rather unusual. Increased growth is normally observed under those conditions. Now, as to why you would get increased growth over the roadways, I am sure I have no answer to that. What was the depth of the soil that you put over these roads?

**R. Toyofuku:** I'm not so sure how much was put on. It wasn't too deep, up to four or five feet.

**R. P. Humbert:** Well, a couple of feet, if that was the depth, certainly would be adequate to take care of cane requirements at that age. Now, by comparison, the leaf freckle areas in Field 40 of Grove Farm are trying to exist on depths of soil of five or six inches.

**H. F. Clements:** A lot of the lime used in the mill would also come out with the mud press, and I just wonder if it wouldn't disturb the pH there, if he was having trouble

**D. S. Judd:** If the ditch was filled in to a greater depth, any lime or lack of nitrogen would be more evident in the ditch than in the field where the layer was much shallower.

**R. P. Humbert:** I think you have had experiences with lime in some of our experiments at Lihue showing the off-color resulting from high calcium additions.

**W. W. G. Moir:** I think there's been a long history on Kauai of that same sort of observation on the matter of following the land.

**A. Stearns:** It might be of interest in that connection that there's an area above the Kohala mill quite a distance up the slope so that you can look up and down the road at it. For a number of years it has been obvious that there is a strip right down across the field. I happened to be talking to Bill Wiley who has been in that area for many years and asked him what caused that. He said, "There used to be a pipe line down across the field there to a hydro plant and about 18 years ago we dug the pipe line up and put the soil back. The only thing that anyone can identify as having happened was that the soil was dug up and put back down again." I think it points up something that might be looked at from a standpoint of field renovation. With so many of our fields cropped so long, we have wondered whether there was a complete disturbance in the soil down to a considerable depth where it might make a difference. Apparently this one lasted for 18 or 20 years. You can still pick the spot right down across the field.

**R. P. Humbert:** Where drainage is a problem, that disturbance of the soil to deeper depths is often beneficial. I know the pineapple people had experience in their wetter experiment station areas where they disturbed the soil to a depth of around four feet, and the improvement in the growth of the pineapples with no other treatment was very marked.

**H. F. Clements:** I should like to make an observation or two. One of my bad things in life is that every time I go to a plantation, I am taken to some place where a strip is looked at, and it's because of a roadway or because of a canal, and the growth is better about as often as it is poorer. Actually, at HC&S, for example at M. A. Company, their virgin lands have given them very, very excellent cane yields; so there the problem becomes what constitutes virginity of soils. And, again, I don't know the answer to it. In fact, we've actually plowed up several acres with a ditcher, going down, I think it was six or eight feet, to work this soil up and put it right back in again, and there we didn't get a thing to show. I wish somebody would come up with an easy way to decide just why things are so. At Maui Ag there is a road bed that was filled in. Well, you can see that green streak from the airplane or from the hill, and then you can go to another place where the roadway growth is very, very poor. Now, obviously my explanation always is like this: that in the deep road cut, we put in all the fine top soil and hence we're getting good growth. Where the growth is poor, well, we didn't work up the bottom as well there so we have a tight subsoil, when, actually, I haven't the slightest idea of what the difference is.

**Jack Larsen:** I was interested in your iron deficiency symptoms on your ppm iron of the different parts of the plant. We have a new field put in at Hawaiian Ag and there were distress symptoms of manganese showing up in spots all over the field. Comments from Dr. Clements and data from Tommy Jones here indicated that manganese showed about 4 ppm in the leaf blade and iron was about 10 to 15 ppm. There was no decrease in growth. I was just wondering how you got that high ppm iron in complete iron deficiency.

**R. P. Humbert:** Well, that is a problem which we certainly do not have the answer to at this time, Jack. We have analyzed cane that is obviously chlorotic in limestone areas and coral areas and after ratoons what is called ratoon chlorosis. Often, we get relatively high levels of iron at that particular stage. Now, our interpretation at the moment is an improper iron-manganese ratio, which I discussed. In this case, even though we had a relatively high level of iron in cane, the much higher level of manganese accounted for the iron deficiency or manganese toxicity symptoms.

**Floyd Ashton:** Roger, do you feel that insufficient amounts of essential elements can cause loss of yields without actually causing physical deficiency symptoms?

**R. P. Humbert:** Yes, I think that you probably wouldn't be able to measure them statistically, but certainly I believe there is a retarded growth as an element becomes limiting prior to the development of marked deficiency symptoms so that they can be diagnosed as such. Dr. Burr, would you like to comment on that further?

**G. O. Burr:** I think it is our point of view that frequently you can slow growth before you can see outward symptoms.

**Question:** Dr. Humbert, I would like to ask if you have any data on zinc. Can you give me an idea of what the levels of zinc were in your no-zinc vs. complete pots?

**R. P. Humbert:** The zinc data on the complete were 33 ppm and minus zinc were 23 ppm. Now, that corresponds very well, very closely, to the analysis of some 125 samples of field cane to date. We have had zinc levels running up as high as 100 ppm on Kauai. Just as a matter of interest, I might say that the copper levels in the complete were 10 ppm and in the minus copper were 5. In molybdenum they were 3.4 ppm and minus molybdenum were 2.6. Now, that's very high. We normally get levels below 1 ppm in molybdenum in field cane. Boron also is below 1 ppm in most field cane samples. In some of these studies we got up as high as 1.8 ppm boron.

# PLANT ANALYSES AS INDEXES OF NUTRIENT AVAILABILITY AND ADEQUACY

GEORGE O. BURR\*

## INTRODUCTION

Undoubtedly all scientists connected with the plantations and the Experiment Station have as their common objective improvements in crop control to give the highest precision consistent with economic returns. Foliar diagnosis is a branch of plant science which still has many generally recognized shortcomings. Assuming that a given sample is truly representative of the whole plot or field, there are many uncertainties associated with the interpretation of analytical values found at any moment. The chemical composition of a tissue is affected by age, climate, soil type, moisture, and interactions between the various elements, as well as by the supplies of the elements available to the plant.

When to those factors affecting the composition of the tissue is added the fact that a single six-stalk sample is probably not very close to the true average for the field, one is often forced to settle for an estimate of current conditions which may be little better than could be given by an experienced crop appraiser after a general inspection of the crop. The point is illustrated in Figure 1 with a summary of a study by Borden\*\* of variability in six-stalk samples collected at Lihue Plantation Co. and Oahu Sugar Co.

A large literature has accumulated on the subject of foliar diagnosis for the purpose of determining plant food requirements. However, this discussion will be limited to data obtained locally from plots at the Makiki Station and in plantation experiments.

The first problem is to find a plant tissue which responds in a predictable way to the supply of food available. The range and reliability of the response must then be determined and related to yield. When this has been done repeatedly over a range of conditions with respect to soil, climate and season, it is possible to set analytical values above which economic gains may not be expected. In the following discussion, analyses of different tissues of the same plants will be compared, and data will be given which suggest in a preliminary way the limitations of the method.

## DATA AND DISCUSSION

All of the nitrogen and potassium samples came from Group Test 11, often called the Amfac test. In this test, there were applied three levels of nitrogen (0,

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\*\* R. J. Borden, 1952. Annual Report, Experiment Station, HSPA, p. 30.

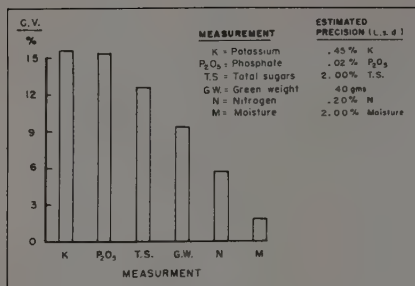


Figure 1

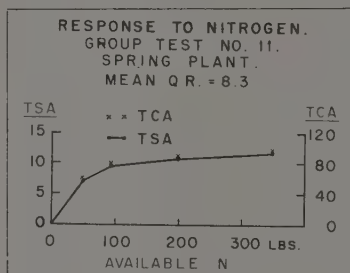


Figure 2

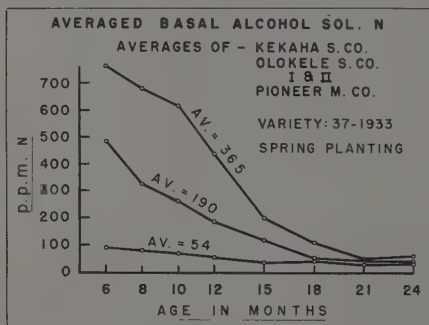


Figure 3

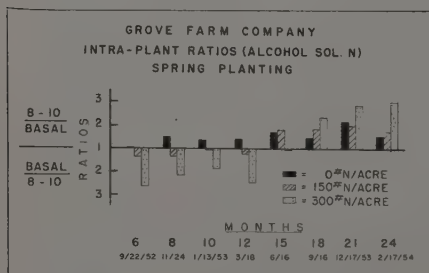


Figure 4

150 and 300 pounds per acre) and three levels of potassium (0, 200 and 400 pounds K<sub>2</sub>O per acre). All plots received phosphate at the rate of 200 pounds P<sub>2</sub>O<sub>5</sub> per acre. The data used here are from the spring plantings of the following seven plantations: Grove Farm, Kekaha, Lihue, Olaa, Olokele, Oahu Sugar and Pioneer Mill. In addition to phosphorus data from the Amfac test, there are included also phosphorus and calcium data from tests on other plantations. Blade and sheath analyses were done on the usual leaves, Nos. 3, 4, 5 and 6.

## Nitrogen

Average yield response to nitrogen in the spring plantings of the Amfac test is presented in Figure 2. The yields in TSA are plotted against nitrogen initially available plus nitrogen added. It is estimated that the zero N plots picked up 50 pounds of N from the soil. The results, including those for the Olokele plots which received 44 pounds N, lie on a smooth logarithmic curve.

Another point of interest is that when all the N is applied early (five months), high N has no effect on Q.R. This was to be expected from the analytical values, since all the excess N was used up long before harvest time. Basal alcohol-soluble N (ASN) is a very sensitive indicator of excess N in the soil. Figure 3 shows that

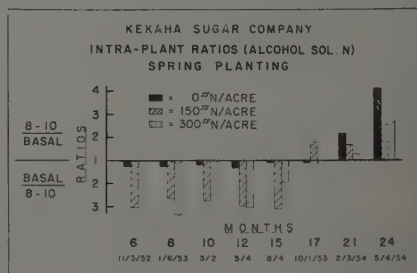


Figure 5

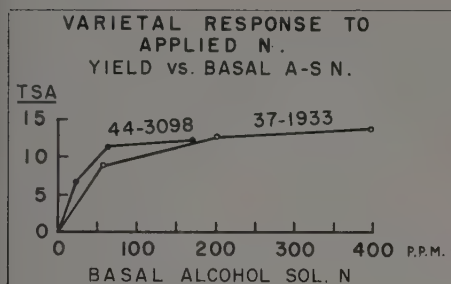


Figure 6

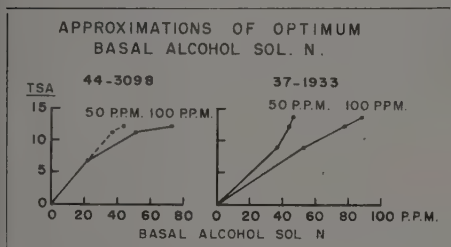


Figure 7

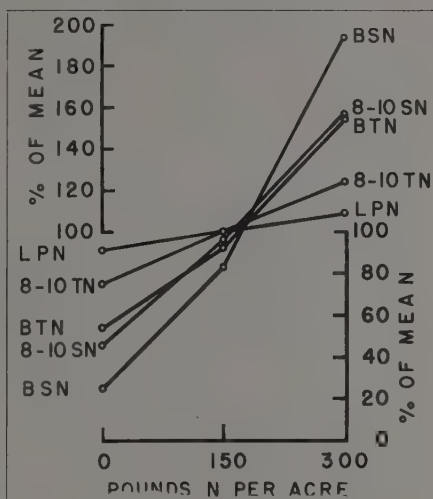


Figure 8

luxury feeding was over by 18 to 21 months in the 150- and 300-pound N plots, respectively.

Another measure of adequate feeding is the intra-plant ratio of ASN. The Kekaha plots were on soils high in available N, while the Grove Farm plots were on soil very low in available nitrogen. The ratios between basal and 8-10 internode values for nitrogen are shown in Figures 4 and 5. When there is marked nitrogen starvation, the ratio goes above the unit line. At Grove Farm, the zero N plots had crossed the line by the sixth month. One hundred and fifty pounds of N were never sufficient to give a large excess of ASN in the basal joints. The yield at Grove Farm showed a much greater limitation due to lack of nitrogen than did the yield at Kekaha.

Varietal differences in analytical response to applied nitrogen are striking. In the Amfac test there were four plantings of variety 37-1933 and four of 44-3098. The average yields are plotted against basal ASN in Figure 6. Variety 37-1933 accumulated much higher levels of ASN and reached the yield-saturation point only at these high concentrations. Levels of basal ASN to which yield responses are found are shown by a method of approximation in Figure 7. Here it is seen that 50 ppm of basal ASN impose no growth limitations on variety 44-3098, whereas approximately twice that level of N is needed for variety 37-1933.

The sensitivity of a tissue as an indicator of available nutrients can be expressed as a slope by plotting analytical values against the levels of nutrient supplied. This has been done for nitrogen in Figure 8. In order to get all values on the same graph, they have been plotted as percentages of the means for the three nitrogen levels. Each point is the mean of 144 analyses representing crop ages of 6, 8, 10, 12, 15 and 18 months. Total and soluble N were determined on

TABLE 1. SUMMARY OF RATIOS OF ACTUAL % DIFFERENCES  
INDUCED BY 150 LBS. N TO % L.S.D.s

Locations	Basal TN	Basal ASN	(8-10) TN	(8-10) ASN	LP TN
Lihue.....	7.4	7.1	5.1	5.0	6.4
Grove Farm.....	13.9	6.4	6.2	6.2	5.0
Kekaha.....	6.8	6.4	4.0	10.1	0.4
Oahu.....	6.9	4.6	6.7	4.6	4.5
Pioneer.....	9.8	9.4	7.8	7.1	3.5
Olaa.....	5.5	5.8	3.5	2.8	2.0
Mean.....	8.4	6.6	5.5	6.0	3.7

the basal and 8-10 internodes and total N on leaf punches from the blade. It is clear that over this 12-month period, 150 pounds of N changed LPN 9 per cent while it changed basal soluble N (BSN) almost 100 per cent. If the variability were no greater for the more sensitive tissues, they would detect smaller changes in available N. The analysis given in Table 1 brings out these comparisons. Assuming that a change of one LSD can be measured reliably, the per cent change due to 150 pounds of N is divided by the per cent LSD's, giving a figure which expresses the relative sensitivity.

Location is a factor of great importance. For example, if the entire experiment had been done at Lihue, the five tissues would have been declared of about equal precision, i.e., an addition of 25 to 30 pounds of N could be detected. However, if the experiments had been done at Kekaha only, it would have been concluded that the stalk is an excellent indicator while the leaf punch is practically worthless (over 300 pounds of nitrogen were needed to give a measurable increase in LPN). Such a conclusion would have been in error and absurd in view of the useful purpose it has already served.

This preliminary statistical treatment\* indicates that, on the whole, stalk N is a more reliable nitrogen index than is leaf N. Further analysis of the Amfac test data is in progress and the stalk analysis procedure is being applied to new tests.

### Potassium

Amfac test data for K are presented in Figure 9 by the same method used for N. Sheath K is found to be less responsive to potassium fertilizer than stalk K. Statistical analysis of relative reliabilities is now in progress. These figures are the average values of 144 analyses of cane from 6 to 18 months of age.

In Figure 10\*\* are plotted the K responses measured in tests on the individual plantations. The analytical response to added fertilizer is remarkably uniform in spite of the wide range of absolute values resulting from variable levels of soil K on the different plantations.

Gains in sugar due to K fertilizer are shown at the right of each plantation. Yield increases due to K are shown for all the plantations except Pioneer Mill and Oahu Sugar Co. By this simple analysis, the critical level of K during this 12-month period is seen to lie between the X plots of Pioneer Mill and Kekaha plantations.

\* Dr. D. D. Mason, visiting Head of Experimental Statistics, directed the statistical work.

\*\* The K values shown in the ordinate must be multiplied by the factor 1.3.

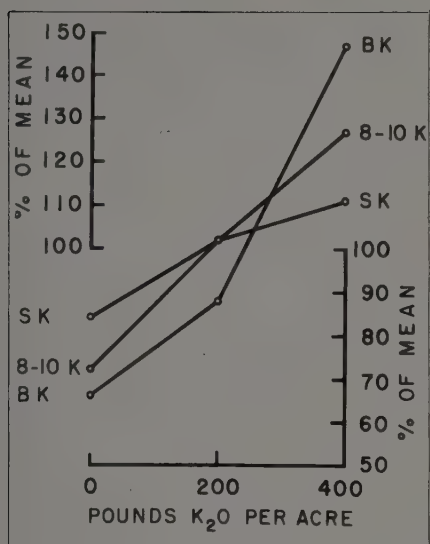


Figure 9

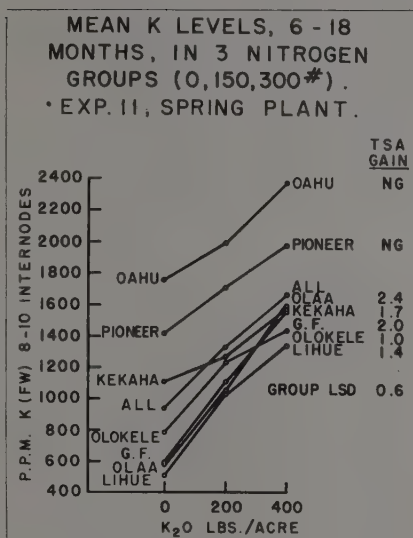


Figure 10

## Phosphorus

The absolute levels of total P and inorganic P in four plant parts are given in Figure 11\*. It can be seen by inspection that the percentage of analytical response to 200 pounds  $P_2O_5$  per acre is much greater in the stalk than in the leaves and sheaths. The data are analyzed statistically in Table 2. Total P of the leaf blade gives a response significant at the .05 level, but the other leaf analyses are not significantly changed. In contrast, the stalk responses to phosphorus fertilizer are highly significant. To date, the 8-10 internodes in many phosphorus tests have been analyzed and they continue to serve as a highly reliable index to applied phosphate.

## Calcium

The 8-10 internodes from a calcium experiment at Hakalau were sent to the Chemistry Department for calcium analysis. Corresponding sheath data were

TABLE 2. RESPONSE TO PHOSPHATE FERTILIZER

Olaa Expt. 101(a)					February 3, 1954			
200# P <sub>2</sub> O <sub>5</sub> Added August 1953								
Plant Crop Gave Significant Yield Gain								
	Blade 4		Sheath 4		8-10 Internode		Basal Internode	
	Tot.	Inorg.	Tot.	Inorg.	Tot.	Inorg.	Tot.	Inorg.
200# P <sub>2</sub> O <sub>5</sub> .....	2660*	780	970	590	530	270	480	250
X (NO P).....	2480	680	850	520	290	140	310	140
Diff.....	180	100	120	70	240	130	170	110
LSD.....	160	..	..	..	80	60	30	60
Diff./LSD.....	1.1	..	..	..	3.0	2.1	5.7	1.8
Sig.....	.05	ns	ns	ns	.01	.01	.01	.01

\* ppm P Dry Weight

\* These data are taken from analyses by Miss Constance Hartt.

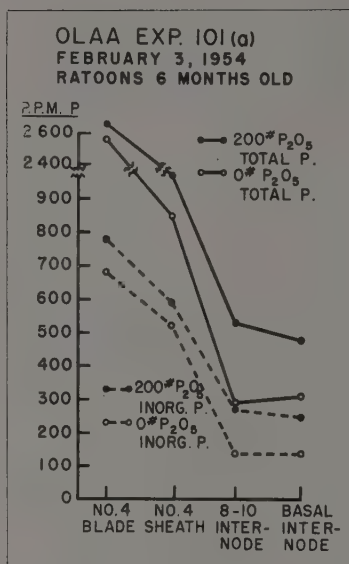


Figure 11

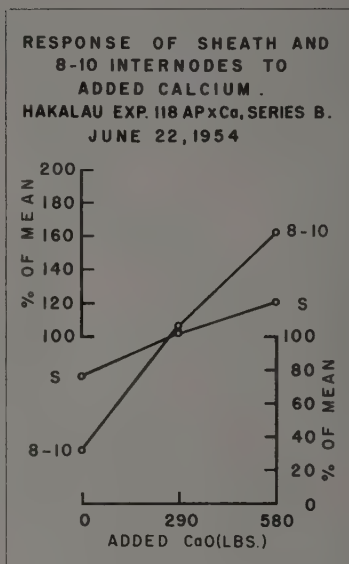


Figure 12

submitted by the plantation laboratory. The results are shown in Figure 12, where it is apparent that the stalk is more sensitive than the 3-6 sheaths to applied calcium. The calcium data pertaining to the 8-10 internodes were subjected to statistical analysis with the results shown in Table 3. The remarkable regularity of the stalk samples from six replications indicates the possibility of detecting as little as 20 pounds CaO per acre.

#### EFFECT OF N APPLICATION ON P AND K

Before concluding this discussion, there is one striking effect to which attention should be called. When nitrogen is applied to the soil, the P and K content of the 8-10 internodes is greatly decreased. The effect on K is summarized in Figure 13, where average values for all Amfac plantations for the age period of six to 18 months are shown. Both cane varieties behave in the same manner. The rising curves give the 8-10 internode response to applied K<sub>2</sub>O (top of chart). All

TABLE 3. RESPONSE TO CALCIUM FERTILIZER  
Soil pH 4.7; Exch. Ca 60 P.P.M.

Hakalau Exp. 118 AP x Ca, Series B 6 Reps. 5 Stalks Per Sample				
Treatment Lbs. CaO/A	Sheath Ca ppm	Diff. ppm	8-10 Ca ppm	Diff. ppm
0	1070		180	
290	1440	370	605	425
580	1710	270	925	320
LSD				25
Ratio Diff./LSD (590 Lbs.)				30
Lbs. CaO for 1 LSD				20

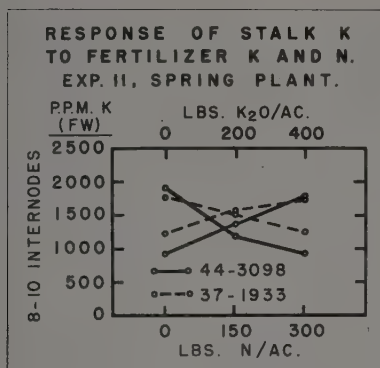


Figure 13

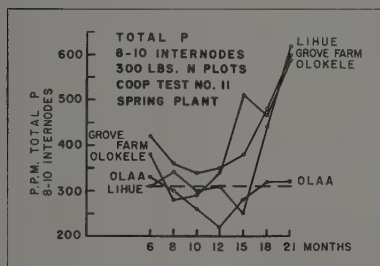


Figure 14

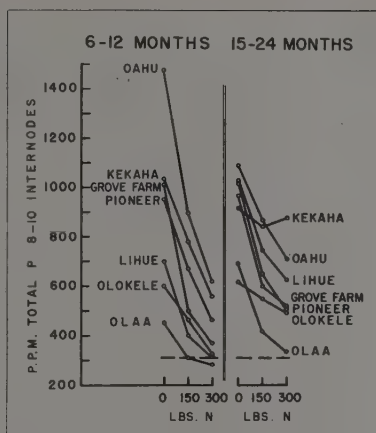


Figure 15

nitrogen levels are included in the falling curves which show a decrease in 8-10 internode K as nitrogen is increased. The two sets of curves have approximately equal but opposite slopes.

This means that for every pound of N applied to the crop,  $1\frac{1}{2}$  pounds of  $K_2O$  must be applied at the same time in order to hold the 8-10 internode K constant. When K is near the critical level, the application of N alone may induce a K deficiency.

The effect of nitrogen on P is of a similar magnitude. Figure 14 shows the depression of 8-10 internode P by nitrogen applications. The effect is extremely uniform, regardless of the absolute level of 8-10 P which depends upon the supply of available soil P. In the first season, while nitrogen is still in excess, the root systems small, and the growth rapid, the 300-pound applications bring levels of P on some of the plantations down to that tentatively set as critical—310 ppm in 8-10 internodes. The data for these plantations are plotted in more detail in Figure 15. Note that for several months of the best growth period, cane on at least three of the plantations may have experienced a phosphorus deficiency despite the application with the seed of 200 pounds per acre of  $P_2O_5$ .

In conclusion, it must be emphasized that this is essentially a progress report. After more data have been accumulated and analyzed, a more critical review will be written with citations from the literature on foliar diagnosis of nutritive requirements. However, it can be said at this time that this preliminary examination of the data shows promise that stalk analysis and other changes in current methods may improve the control of fertilizer applications and the diagnosis of the nutritive state of sugar cane.

## DISCUSSION

**H. F. Clements:** I want to make a general statement of personal policy. There is no doubt in my mind that the time will come that we will change crop logging. We'll probably change the tissue; we'll probably change the times of sampling; we'll probably change very many things. There has never been a system developed which hasn't been modified or changed or forgotten. My system, being that of a mortal, probably will go in one of those three ways. I certainly want to say to Dr. Burr and to the people here at the Station, I think it's very fine that they are doing all this work that they are doing. At the same time, I don't want to be in a position of having to say "no" all the time—let's see your data. As a statement of my personal policy, then, I would like to say this: that when you people here have something which you're sure of, and are willing to recommend positively, and are willing to give a completely objective and scientific report, I will guarantee you that we will put it to work on the plantations. And I will also guarantee you that, if you want, I'll get hundreds of acres here, or there, or the other place, which you can manage and grow the sugar. Now, I don't mean that in any nasty sense at all. I think one of the most important contacts that I had early in the development of the crop log was the early contacts at Ewa and Waialua and Kohala, where I made blunder after blunder, but we learned from those blunders, and we finally developed a system that we think is working. So that's my statement of personal policy. Now, as an additive to that, I'd like to say that I'm not going to accept the first thing that you come up with. In other words, it does have to be better, and it does have to be practical, and it does have to be applicable to work under the very many conditions. Now, as a demonstration, George, I don't doubt the figures that you have presented at all. I recognize you as a scientist, and your being one means that the figures that you present are completely fine. Now, there are, however, evidences which I receive which don't quite fall in line with what you have given. I think, for example, that your ignoring the tissue moisture of the plant is ignoring one of the fundamental things of the plant. Now, you can have high phosphate in the stem, and if you don't have adequate moisture, you may still have a deficiency up top where growth is occurring, or where photosynthesis is going on, or where any or all of these things are happening. I think, also, you are ignoring an important thing when you are ignoring the total sugar level of the sheath. That, to me, is an integrator of the plant's fitness to its environment, and after all, that's what the plant is in—it's in an environment, and if we ignore those two things, I think we are ignoring very important things. In fact, I don't believe that going back to single nutrient determinations is going to be an advance over what Walter Thomas contributed, which contributions, of course, go away, way back to the middle 20's and 30's, and from there on. Now, the one big point which I get out of your data seems to be about like this: that you consider your node to be about like this—you switched on me—this is on alcohol-soluble nitrogen—to be sharper, apparently, than your leaf nitrogen. Well, now, here at Hilo Sugar, for example, and I am quoting from a letter which Roger Humbert wrote to Larry McLane giving the results on some analyses which had been run on samples that Roger, I think, had collected at Hilo Sugar in what we call a Jamaican test. In other words, it was a test in which the A plots received 250 pounds of nitrogen, the B plots, which are supposed to be more or less normal plantation practice, had 208 pounds of nitrogen, and the C plots showed 165 pounds of nitrogen. Now, the alcohol-soluble nitrogen fraction on this—I don't know whether this is basal or 8-10—it doesn't seem to be designated here, but I think it's basal—now, the basal nitrogen shows these figures expressed on the dry-weight basis. (Blackboard presentation). In other words, that doesn't seem very sensitive to me, somehow. Now, the leaf nitrogen on that same series showed this: (Blackboard presentation) and I'll grant you that this isn't very sensitive, either, but at least it comes closer to being in the right direction. Leonard, if I run a little overtime, I'm going to have about 15 minutes to spare this afternoon, and I can give that to somebody, but I consider this a rather important sort of thing to do. Now, the thing is this: if we standardize the leaf nitrogen, the same as I indicated from the sheath phosphorus yesterday, we come up with an answer which standardizes the nitrogen level for the moisture level that we're dealing with. Now that's in Field 23 at Hilo, a makai field, and 43 is a mauka\* field. Now, here with the same setup, and the same treatments, the alcohol-soluble nitrogen showed for the plot: .700; .909 and .729. In other words, here the highest treatment has the lowest reading. The middle treatment had the highest reading. Now again, and that is, when we take the leaf nitrogen on that basis, this is what we got: 2.25, 2.09 and 1.98. Now again, I ask you, that doesn't look very sensitive to me. Now, there's one other important point here. I'm not sure that this figure here can be correct. That's so much higher—in fact, it's actually higher than what we usually find in the meristem. But assuming that it's correct, we get an enormous difference between this and this. Now, on our actual field samples—that is, normal logging samples that we have to deal with—the figures were like this: for the field sample, this field here showed a nitrogen reading of 2.81, which is very high, and this one showed 2.83. In other words, again I don't think the leaf nitrogen has led us astray. Now, it's true that these leaf nitrogens over here, while they seem to give us the better correlation with the actual treatment than your alcohol-soluble nitrogen—and those, incidentally, were done here at the Station so they are their own figures—the difference between here and here is very important, of course, and very impressive. The question is a practical one that wouldn't bother us very much. We aren't interested at these levels, anyway, in putting on more fertilizers at that stage; we only get interested when it gets down to the 1.85 or the 1.80 level. So, that's one kind of evidence. Now, there's another kind of evidence. Now, I should like to present this again. In Puerto Rico, at the University Experiment Station there, there is some very excellent work being done on crop logging. In fact, they've thrown out all their soil analyses

\* (Makai means toward the sea; mauka means up or toward the mountain.)

as a guidance to fertilization, and are shifting completely to the crop log. There are three men, and you'll probably hear more of them, so I think I'll just put their names on the blackboard. Samuels\* is an agronomist; Capo and Bangdiwala. Capo is a plant physiologist and occasionally gets into administrative work since he happens to be Assistant Director; and Bangdiwala. Now, they have gone to a standardizing figure on all of these nutrients. They use the crop logging in its entirety. They use the same tissues that I've used and have proved. Now, here is what comes from their work. They went after this nitrogen business, recognizing that there were times when the nitrogen level of the plant didn't seem to behave the way it should behave, and so they made quite a thorough study of the whole thing and came up with an analysis, a statistical analysis which I think is a very important contribution to the whole matter of crop logging. They took Borden's data—you remember Borden had these experiments out at Waipio—those data have been quoted repeatedly here, and in those data, Borden, like Dr. Burr, wasn't able to show a very great sensitivity to leaf nitrogen. And so these people took those data, in addition to many of their own data, and they reported those results. Now, for example, there is the sort of variation that you are likely to get, the plant cane, the first ratoon, and the second ratoon. Now, the straightforward leaf nitrogen figure for the 0 plot of nitrogen showed .98; for the 100 pounds of nitrogen showed 1.36, and for the 160 pounds of nitrogen showed 1.46. Percentagewise, yes, not much difference there. On the first ratoon, .90; 1.22; 1.38. On the second ratoon, 1.05; 1.36; 1.36. Now, obviously, that is not an impressive array of figures. In other words, with this method we can't pick up, so we would be told, the difference between 100 and 160 pounds of nitrogen. Now, when these people developed their equation, and their equation is a comparatively simple one, where  $N_s$ , and that is the standard nitrogen, is equal to  $S_t$ , that's the actual nitrogen, minus .0541, and because of the fact that Borden didn't report the sheath moisture from the sheath sample, they used the cane stalk moisture but they, in their paper, show that the sheath moisture is far more sensitive than the stalk moisture, and that's what this figure is: the actual moisture of the stalk plus 3.0978. Now, when they do that, these figures here change. This one becomes 1.06; 1.07 and 1.06. In other words, a very good check in the three crops. The next periods here, 1.32; 1.28 and 1.27. Again, there are three crops compared, quite happily, one with the next. And then, finally, our 160 pounds of nitrogen shows 1.42; 1.38 and 1.38. In other words, by standardizing this nitrogen level, we too can sharpen up the leaf nitrogen, if that's what we like. Now, I have had here a whole series of equations which we could use. In fact, I'm almost tempted to make you use them. But, at the same time, I think it rather would complicate things, and unnecessarily so. I must confess, Dr. Burr, all this confusion that you profess to, I don't find at the plantation level. At the plantation, the usual procedure that we go through is this: I come and we go into the manager's office and all the logs are there, and we sit down and we go over those logs. Now, it is very seldom that I can pick up anything that the men haven't already picked up. In other words, they're really hep to it, and they're watching their fields and all that. So, at the moment, I'm not going to give you those equations, because, frankly, I don't think it would—the little sharpening that we'll get isn't very important. Now, one other point, and then I will sit down. Now, again, I want to strike at this basic difference between what the Station is now doing and what the crop log is based on. Essentially, what the Station's plant physiology is recommending, or thinking about recommending, is that we would drop sheath moisture, we would drop sheath sugar, we would drop sheath everything, and move to the stalk, and take just the elements there on a single sample. Now, in the data that I showed you yesterday, I showed you the tendency of plants to route nutrients from the older part of the stalk to the new growing regions. Now, obviously the important parts of the plant, as far as industry is concerned, are obviously first the growing part, that is the meristem, with the green tissue of the leaves, the photosynthetic tissue, including transpiration, because that's an important part of your plant problem, and then, of course, storage. Now, we cannot assume, just because we find a certain level of nutrient in the stem, that we are always going to have a corresponding level of nutrient in the upper tissue. In other words, it's quite possible to have, on the one hand, an adequacy level in the stem and a deficiency level at the top, and it's also quite possible to have it the other way around, where we have a comparatively high level up above and a low level down below. In other words, picture the situation—let's say that here is this reservoir. Essentially, George, what you're measuring when you're measuring the nutrient in the stem—you're measuring what's left. You're not measuring what's up front, where the work is going on. Now, what's left is determined not only by the level of the nutrient, but by the vigor of that plant, and you ignore the vigor, also, completely. Supposing we have an extremely vigorous plant growing and let's say it's producing a tremendous amount of growth. It's quite possible that we can have less than normal amounts of phosphorus left down in the stem. But, the only thing that we've really interested in is how much is up there where the work is going on. In other words, here we're actually comparing what's back here, where nothing's happening—that is, it's standing still. It isn't going to do anything until we burn it off and squeeze the juice out of it. On the other hand, we can have a circumstance where we would have the same sort of a business with a comparatively high phosphate level and deficiency up here. Now, I'm not manufacturing this out of thin air. I have here an actual case which I picked more or less at random—in fact, I don't think it would be hard to get many more similar cases. Here we have a Kailua grown crop and I'm going to give you first the internode 7-9 that happened to break that way. In June, July, August, September, October and November—those are the actual periods normally

\* G. Samuels is Plant Physiologist; B. G. Capo is Head of Agronomy and Horticulture and Assoc. Director for Research; I. Bangdiwala is Asst. Statistician, at the Experiment Station of the University of Puerto Rico.

that we would use for making our reading on phosphate—on these internodes, for the Kailua crop, the readings were as follows: (Blackboard presentation) Now, the Waipio plot gave this reading: I don't know the figures for that one. Now, on the basis of your stem phosphate, what would you say? Certainly, they're about a standoff, aren't they? And yet, the sheath figures were as follows: for the Kailua, the sheath figures were .063, .064, .065, .086, and all of you who are used to using a log will recognize that as a rather serious deficiency level. On the Waipio side, however, the figures are as follows: .093, .091, .082, .118, .130. Well, in other words, here then is a situation. Now, the big difference here is that our Kailua plants were not doing very well. It wasn't a vigorous growth, and it indicates to you that this plot here gave 122 tons of cane per acre, and yet we would say that it's at or near the deficiency phosphorus level, and I don't think it is. Up front, there was a great excess of phosphorus, even though in the reserve there wasn't an awful lot left. Well, that's the kind of material that I have to look at, George, so if I act a little stubborn once in a while, it's because I have some data, eh?

**L. D. Bayer:** I'd like to make a comment or two before asking for other questions. I would like to emphasize to you, Harry, that the objective of this seminar is not to put crop logging on trial. We felt that folks were interested at this particular time in coming together and see what our respective data are, where we might fill in gaps and, if possible, where there might be avenues of getting together. The data that Dr. Burr has presented—I can assure you that we do not hold back any particular selective data—are the facts that were obtained. Also, Dr. Burr was not trying to sell you anything. He was pointing to the fact that we obtain them at the present time as a means, perhaps, of getting a little more sensitivity, if that is possible. He's not so sure himself of some of these particular phases.

**G. O. Burr:** I would just like to say, Harry, that there was one statement that you made about what we were trying to do that was certainly far out of our minds. For instance, you said we throw out moisture, sheath weight, leaf sheath moisture. I have been looking over data and I have had the feeling that probably some of the most valuable indicators of growth we have are these green sheath weights and moistures. Everybody throughout the world recognizes that with a good top weight, you're likely to be having good growth. In fact, that is the sole diagnostic figure used in some places. Our objective is to measure the reliability of responses to what is in the soil. Then, if possible, as the plant comes into these more deficient levels, find the point where we think analyses are beginning to show deficiencies. Now, with high reliability, our chances of finding that point will be good. Another point that was made was that we measure at a place so far away from the point of use. That is not quite the way I picture it. We are measuring a source of supply. Suppose you were laying out the ideal experiment in culture solutions. Your source of supply is measured by the analysis of the solution. Now, that's not possible here. We don't know what the soil solution is, and so we're measuring the nearest thing to a source of supply that we can measure. Now, if there's no correlation between the source of supply and growth, then it's out of the picture. If there is, then it's good. There's one other point I would like to make in referring to Samuel's work, and that, of course, is one great error in biological procedure, to take that sort of data and set up an equation and then show that the data fit the facts. Now, the equation was set up from the data and then translated back to the facts. Of course, it would have to fit, otherwise you couldn't make the equation. And, of course, that could not be transferred to our conditions here.

**H. F. Clements:** I would like to challenge that point.

**G. O. Burr:** I don't think personally we should carry on a discussion like this here, but that's just a point of view.

**H. F. Clements:** No. If statistics mean anything, George, it's data on which you determine reliability. Let's determine the means by which to find the contents.

**G. O. Burr:** Don't you have trouble, for instance, in applying your equations from Ewa to Kohala?

**H. F. Clements:** Indeed I don't. They are remarkably good. I'll show you that this afternoon.

**G. O. Burr:** Well, I thought you had to use different values.

# SOIL ANALYSES AS INDEXES OF NUTRIENT AVAILABILITY

A. S. AYRES AND H. H. HAGIHARA\*

The methods employed at this Experiment Station for the analysis of soils prior to 1930 were slow and involved. Moreover, each sample was analyzed not only for "available," but also for "reserve" and total supplies of the major nutrients.

"Available" nutrients in that period were extracted from the soil with a one per cent solution of citric acid, while a measure of the "reserves" was obtained by extraction with strong hydrochloric acid. Fusion of a soil-sodium carbonate mixture and extraction of the cooled melt with hydrochloric acid made possible the determination of the total quantities of nutrients in the soil. pH data were obtained accurately, although laboriously, with the hydrogen electrode.

With the advent of the so-called "rapid" or "approximate" tests, these time-honored techniques fell into disuse. Modifications of methods developed for temperate zone soils and popularly known as RCM (Rapid Chemical Methods) became standard procedures for the estimation of soil fertility at the Experiment Station and in plantation laboratories. The more precise methods of analysis, requiring greater skill and more elaborate equipment, were reserved for fundamental soil research.

The need, on some of the more highly-leached soils, for greater sensitivity in the determination of nutrient levels than was provided by RCM, led in 1950 to the general application of research techniques to the determination of soil needs. Following are brief descriptions of these methods, which currently are employed at the Experiment Station in the yearly analysis of some 4000 soil samples.

## DESCRIPTION OF METHODS

The pH of a paste prepared from air-dry soil is quickly determined by means of a laboratory model pH meter, employing a glass electrode and sleeve-type calomel reference cell.

Where something is known regarding the pH-base relationship of a soil and the ultimate pH, this measure of hydrogen ion activity is of inestimable value as a first approximation of levels of exchangeable calcium and magnesium on soils of low base saturation. In this laboratory, analysis for these bases hinges upon the pH of the soil.

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\* Respectively, Senior Agronomist and Assistant Agronomist, Experiment Station, HSPA.

## Phosphorus

The supply of soil phosphorus is determined by the long and widely employed Truog technique, as modified in this laboratory, with respect to strength of extractant and treatment of dissolved organic matter. Thus modified, it is better suited to some of Hawaii's low-phosphorus latosols, high in organic matter.

The Truog procedure does not extract all of the available phosphorus from the sample. Rather, it measures the concentration of phosphorus which the soil is capable of establishing in the extractant; i.e., the phosphorus supplying power of the soil. This is an equilibrium process. Such being the case, successive extractions of a sample of soil would be expected to yield results not differing greatly from that for the initial extraction, except as the supply of phosphorus gradually became depleted. This is illustrated in Table 1, which shows the results of nine successive extractions of four soils of differing phosphorus content.

TABLE 1. PHOSPHORUS RECOVERED FROM SOILS BY SUCCESSIVE EXTRACTATIONS WITH .02  $\text{NH}_4\text{SO}_4$

Plantation	pH	Phosphorus—in ppm of Soil								
		1st	2nd	3rd	4th	5th	6th	7th	8th	9th
Lihue.....	5.1	12	10	9	9	9	8	9	9	8
Pepeekeo.....	5.1	20	30	31	28	26	20	20	20	17
Kohala.....	5.2	34	57	63	56	53	45	43	42	34
Hakalau.....	4.6	41	48	44	38	35	31	30	31	25

It is apparent that repeated removal of phosphorus did not greatly reduce the ability of the soil to yield phosphorus to the extractant.

Like other techniques employing acid extractants, the method is not well suited to the determination of available phosphorus in calcareous soils. The acreage of such soils in Hawaii, however, is relatively very small.

## Potassium, Calcium, and Magnesium

These nutrients are removed from the soil by exhaustive leaching with normal ammonium acetate adjusted to pH 7.0. They are subsequently determined either chemically or by the flame photometer. Exchangeable potassium and magnesium are much more readily removed from most Hawaiian soils than is calcium. Where calcium is to be included in the analysis, the quantity of the acetate is nearly doubled.

Unlike the situation with respect to phosphorus, the quantities of these nutrients present in the soil in available forms are removed practically in their entirety in the course of the extraction. This is illustrated in the case of potassium in Table 2, taken from a paper by the senior author (2).

The data make it apparent that only comparative traces of exchangeable potassium remained in these soils following the initial extractions.

Although essentially all of the potassium, calcium, and magnesium present in the soil in available forms are extracted by the method outlined, additional quantities of these nutrients, particularly of potassium and magnesium, may become available during the course of the crop. With the two-year growth period enjoyed by most of the sugar cane grown in Hawaii, release of nutrients to a single crop may be very substantial. The liberation of potassium in Hawaiian soils has been extensively studied and reported upon (2, 4).

TABLE 2. POTASSIUM EXTRACTED FROM SOILS BY REPEATED LEACHING WITH N-AMMONIUM ACETATE

Soil Group	Location	Leachings					
		1st	2nd	3rd	4th	5th	6th
		ppm	ppm	ppm	ppm	ppm	ppm
Low humic latosol.....	Makiki	525	12	9	4	4	3
Grey hydromorphic.....	Ewa	390	5	4	4	3	2
Alluvial.....	Wailuku	1325	11	10	4	3	3
Low humic latosol.....	Puhi	125	4	5	3	2	2
Hydrol humic latosol....	Honomu	117	4	4	3	2	2

## Expression of Results

All analyses, except pH, are made upon weighed portions of air-dried soils. Moisture contents are determined and analytical data corrected to the oven-dry basis. Results for the various nutrients are expressed in terms of parts per million (ppm) of soil.

## STANDARDIZATION AGAINST FIELD EXPERIMENTS

Chemical methods for determining supplies of soil nutrients are empirical, the quantity of an element measured depending upon the nature of the extractant and the manner in which it is employed. The results of such analyses are thus without value, so far as the agriculturist is concerned, unless they can be expressed in terms of crop response. In Hawaii, we are fortunate to have available for standardization purposes a substantial number of carefully controlled, adequately-replicated field experiments.

Calibration of nutrient levels in the soils of these tests in terms of response is a project conducted jointly by the plantations, Island Representatives, and the Agronomy Department of this Experiment Station. Immediately after a test is initiated, well-composited samples, representing the tilled layer of soil, are taken in the check plots and sent to this laboratory for appropriate analysis. Analysis is made not only for the element or elements in question, but also for pH and the non-variable major elements, calcium and magnesium, when deficiencies of these are suspected. This insures that the latter are, or will be, present in the test area in amounts sufficient to permit optimum response to additions of the variable elements. At harvest, responses, statistically analyzed, are studied in relation to the level of the particular element present in the soil at the start of the crop. If the test is to be continued, the check plots are immediately resampled in preparation for the succeeding crop.

## Phosphorus

At the time of writing, harvest results from 60 "amounts of phosphate" experiments, many of them repeated, together with their respective soil analyses, were available for comparison. For this purpose, each crop of a given experiment, when it is complete within itself with respect to yield and soil data, is treated as an individual test. This brings the total of such tests to 79. Experiments conducted on abnormally stony or shallow soils are not included.

The results for phosphorus are shown in the form of a bar diagram in Figure 1. Each test is represented by a bar, the height of which indicates the pertinent level of soil phosphorus. The tests are arranged from left to right in order of decreasing phosphorus supply. Indicated also is the "critical range" (18-22 ppm). This is

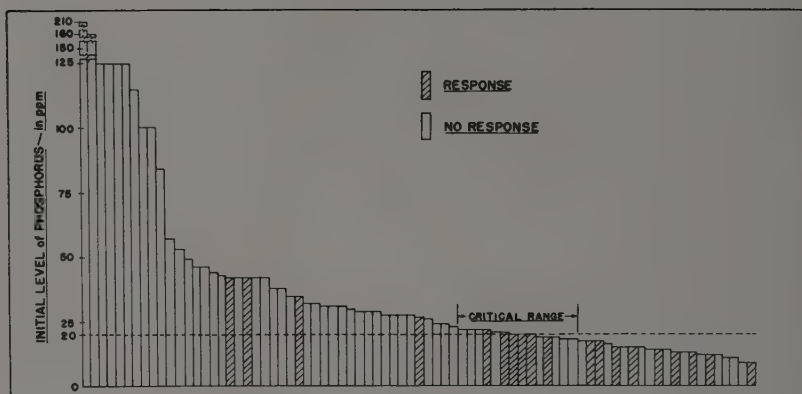


Figure 1

simply the critical level of 20 ppm which has been tentatively employed since the inception of this study, with an allowance of 2 ppm in either direction for errors of various sorts.

Commencing at the very high level of 210 ppm, it is seen that there was no response to phosphorus until the level in the soil had dropped to about 40 ppm, at which point two tests showed increased yields from the addition of phosphate. Between this level and the critical range, yield increases were shown by two additional tests. Thus, of the 44 tests containing amounts of phosphorus above the critical range, 40 indicated adequacies of phosphorus, and four did not.

Fourteen experiments fall within the critical range itself, where response may or may not be expected. Of these, six responded to phosphate fertilization and eight did not. At levels below the critical range, many of the tests showed response, but at least an equal number did not, indicating that for some of the soils represented, the critical level of 20 ppm is too high.

Response in the four tests with levels of phosphorus above the critical range does not appear to be explainable on the basis of the information at hand. Although perhaps without significance, it may be noted that all of these tests were situated on the same plantation (Paauhau).

Several factors may possibly account for the lack of response to phosphate at levels below the critical range. The tests which failed to respond to phosphate at sub-critical levels are all located on the island of Kauai. Kauai soils are the oldest of the Hawaiian group and generally the most highly-weathered. There would seem to be a possibility, therefore, that some condition of growth necessary to the utilization of the added phosphate was in some degree restricted. One such possibility is the supply of exchangeable magnesium which, in some of these tests, was found to be extremely low. In some instances, short cropping possibly explains the lack of increased yields from phosphate fertilization. As seen at the present moment, however, the most plausible explanation of the seeming discrepancies revolves about the widely differing volume-weights of Hawaiian soils.

The critical level of 20 ppm was initially established on the basis of results obtained from experiments on the Hilo and Hamakua coasts of the island of Ha-

waii. For these soils, without exception, this critical level appears to be sufficiently low, all tests from these regions having shown response to phosphate where supplies of phosphorus were below the critical range.

The weight, in the oven-dry condition, of a surface acre-foot of an average Hilo or Hamakua coast soil is probably in the vicinity of one million pounds. In such a soil, a phosphorus level of 20 ppm would correspond to 20 pounds of phosphorus in the surface acre-foot. The corresponding weight of the average Kauai soil is probably twice this value, or two million pounds. A surface acre-foot of the Kauai soil, showing a phosphorus level of 20 ppm, would thus contain twice as much phosphorus as the corresponding volume of the Hilo or Hamakua coast soil. It would not be surprising, therefore, assuming comparable crop requirements for phosphorus, if the critical level for Kauai soils were found to be lower than for the Big Island soils.

It is possible that it may become necessary to establish two critical levels for phosphorus, one for the low volume-weight, ash-derived soils, and a second, lower one, for the high volume-weight soils formed from lava and alluvium. Or, it might prove more feasible to recognize a single critical level and to make suitable allowance for differing volume-weights at the time analytical data were reported. At the time of writing, there are some 30 additional experiments in progress in the phosphorus range from 25 down to 5 ppm. It is anticipated that the results of these tests will serve to satisfactorily clarify the issue.

Critical levels above 20 ppm may be expected on low volume soils where the mass of soil is abnormally low owing to the presence of rocks or to shallowness of soil.

Potassium

Where responses to potash are obtained, they are generally of a higher order than responses to phosphorus. In the presentation of the potassium data it is, therefore, possible to show not only the relationship between the level of soil potassium and response, but to indicate as well the magnitude of the response. The data, based upon 57 experiments conducted on normal, deep-phase soils, 11 of them once repeated, are shown in Figure 2. In an attempt to iron out differences

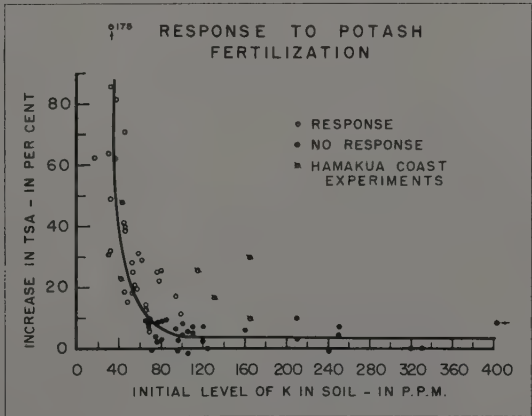


Figure 2

resulting from divergent climatic environments, responses are presented as per cent increases rather than as flat gains in TSA. Except as indicated, gains are shown as measured, irrespective of significance, the significance of each gain being shown in the manner of plotting. The curve relating the level of soil potassium to response is based upon inspection of the data. For reasons which will appear later, four Hamakua coast tests, so designated on the chart, were disregarded in locating the curve.

From an increase of 175 per cent at the extremely low K level of 30 ppm (off the chart) the curve drops almost vertically to about 35 per cent at 40 ppm K. In this very low potassium range, gains from potash were very great. From this point, reflecting progressively smaller increases in sugar, the curve drops more gradually until at around 100 ppm K it becomes horizontal. It remains thus up to the highest level of K (400 ppm), suggesting little likelihood of response to the addition of potash at K levels much in excess of 100 ppm.

We may regard as the region of uncertain response, or the critical range, K values from about 75 to around 100 ppm. Very few experiments in which supplies of potassium were below 75 ppm failed to respond. Without exception, every one of the 24 tests with K levels below 65 ppm responded.

In Queensland, von Stieglitz (13) reported a somewhat lower critical range for exchangeable potassium in relation to sugar cane. The category which he established is approximately as follows:

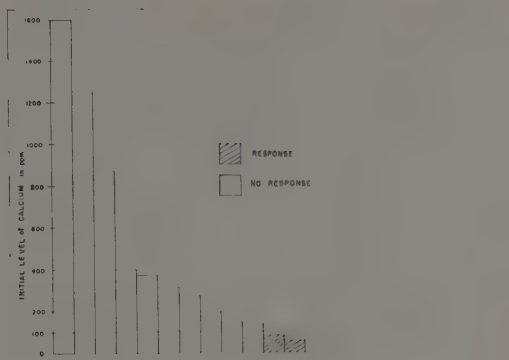
Very low	—less than 40 ppm K
Low	—40–50 ppm K
Medium	—50–70 ppm K
High	—more than 70 ppm K

This lower critical range quite probably results from the fact that in Queensland the cane crop is grown for one season only. Hence, the size of the crop and the demand for potassium would be expected to be less than for Hawaii's two-year crops. Baver and Moir (8), in their observations on sugar production in the Carribean area, note that in Trinidad about 90 ppm K (exchangeable) is considered to be the critical level for this element. For 18-month crops, this figure appears to be in accord with results in Hawaii. The same authors observed that a much higher figure of 150 ppm seems to approximate the critical level for potassium (exchangeable) on the terra-rosa-type soils of Barbados. It has been suggested that the higher level stems from the high calcium content of these soils.

In Hawaii, Magistad (10) reported increased yields of pineapple from potash applied to soils containing 80 ppm, or less, of (exchangeable) potassium. Above 185 ppm, there were no responses. No tests were conducted on soils of intermediate potassium levels.

Until recent months, practically no harvest data pertaining to "amounts of potash" experiments (embracing zero K plots) on low volume-weight soils were available for study. The present concept of the critical level for soil potassium has thus grown out of results from tests on the high volume-weight soils, which is the reverse of the case with phosphorus. As the four Hilo and Hamakua coast tests showing response above 100 ppm K (Figure 2) suggest, the critical level for potassium in low volume-weight soils may prove to be higher than for high volume-weight soils.

Figure 3



The critical level for potassium may be expected to be above 100 ppm for soils containing considerable proportions of rock. The same would be true of shallow soils which overlie lava rock rather than subsoil.

### Calcium

Interest in the supply of calcium in Hawaiian sugar cane soils all but ceased around 1935, following consistently negative results from a considerable number of field experiments employing generally large amounts of lime (9, 12). Seemingly not in conformity with the results of these tests, the senior author (1), employing present methods of analysis, established in 1943 the presence of extremely low levels of calcium in some of the humid region soils of the island of Hawaii. Abundant soil analyses, since 1949, have confirmed this observation and extended it to areas of much lower rainfall elsewhere in the Islands. These results, together with the superior performance of superphosphate over ammophosphate in certain field tests in these areas, served to reopen the question of the calcium fertilization of sugar cane. Field experiments, employing far smaller quantities of calcium than had been used in the earlier tests, followed.

The relationship between the level of calcium initially present in the soil and response to the addition of this element, for a dozen recently harvested experiments, is illustrated in the form of a bar diagram in Figure 3. As before, only tests conducted on essentially rock-free and normally deep soils are included.

Reference to Figure 3 shows a consistent absence of response at the higher levels of soil calcium. It is not until the supply drops moderately below 100 ppm that the addition of calcium results in increased sugar. On the basis of this meager evidence, the critical level for calcium appears to be in the vicinity of 100 ppm. If such be the case, there are in the humid and semi-humid regions of the Islands, thousands of acres of sugar cane land on which increases in sugar might be expected from fertilization with calcium.

### Magnesium

In Hawaii, little has been heard regarding magnesium, except in connection with its reputed adverse effect upon the physical condition of certain Island soils and its antagonism toward other elements necessary to the growth of sugar cane. Little thought appears to have been given to the possibility that it might also be

present at deficiency levels. Yet, in soils which are base-saturated to the extent of only a few per cent, in extreme instances to less than one per cent, and where the level of potassium, although critically low, often exceeds the sum of the other bases, the possibility of such deficiencies must be recognized.

The results of only two field experiments with magnesium are at hand. In neither of these tests was response shown to magnesium up to the maximum application of 60 pounds MgO per acre. Since the levels of magnesium in the soils are unknown, the tests are of little aid in pointing up the critical level for this element. That a need for additional tests exists is clearly indicated in Table 3, which shows how widespread the areas low in magnesium are. Only soils containing less than 100 ppm magnesium are represented in the table.

TABLE 3. MAGNESIUM (EXCHANGEABLE) CONTENTS OF HUMID AND SEMI-HUMID REGION SOILS

Plantation	Expt. No.	Field	pH	Magnesium ppm
Olaa.....	..	6	4.8	97
Onomea.....	..	16	5.2	95
Grove Farm.....	136 AP	H-35C	4.8	80
Kilauea.....	263 A × FP	1	4.6	79
Hilo Sugar.....	..	15	4.8	65
Olaa.....	..	W	4.9	62
Hilo Sugar.....	..	33	5.0	62
Lihue.....	322 AP × K	30 Hm	4.7	55
Pepeekeo.....	68 AP × K	88 A	4.9	36
Hakalau.....	118 AP × Ca	134-1	4.9	26
Lihue.....	342 AP × K	43 Hm	4.3	26
Pepeekeo.....	83 AP × Ca	9	4.9	25
Laupahoe.....	36 A × FP	P 49	4.6	24
Laupahoe.....	31 AP × K	M 68	4.9	22
Grove Farm.....	..	H 39	4.4	21
Kaiwiki.....	..	39	4.7	21
Kaiwiki.....	..	30-2	5.0	17
Lihue.....	324 AP × K	1A-M	4.3	16
Hakalau.....	..	15	4.6	14
Laupahoe.....	SS 64	10D	4.8	11
Pepeekeo.....	..	9	5.0	7

Without experimental data, one would hardly hazard a guess as to the critical level for magnesium. However, the cane plant has been found to take up at least as much magnesium as calcium (11) and it might, therefore, be supposed that the critical level for magnesium would approximate that for calcium. A modifying factor may lie in the fact that magnesium, being present in the lattice structure of some secondary minerals, may, like potassium, be gradually released to available forms. Calcium is not believed to be thus held, and hence not subject to release.

#### EFFECT OF CROPPING ON LEVELS OF SOIL NUTRIENTS

A longfelt need for knowledge regarding changes which occur in supplies of soil nutrients with cropping, has been partially met through successive analysis of soils of experimental areas. The statement that such changes are the result of cropping does not exclude the fact that other factors also operate to alter nutrient levels. However, the over-all effect is the primary concern here rather than the precise role played by the crop alone. Thus far, only plots unfertilized with respect to the element in question have been the subject of study.

## Phosphorus

The data for the zero P plots of 33 twice-sampled experiments (Table 4), almost without exception show measurable decreases in supplies of soil phosphorus as a result of the production of single crops of cane. The decreases are quite variable, ranging from 1 to 16 ppm. One test showed no change, while in another there was an apparent increase of 2 ppm. The average drop for all tests was 5.6 ppm.

When we consider separately the experiments on the humic and hydrol humic latosols of the Hilo and Hamakua coasts, temporarily disregarding certain nonconforming Paauhau tests, we find an additional relationship. In Figure 4, it is thus seen not only that the level of phosphorus decreases upon cropping, but also that the decrease is in proportion to the supply of the element initially present. The relationship, which is highly significant, shows, for example, that at the initial phosphorus level of 15 ppm a drop of about 2 ppm may be expected coincident with the production of a crop of cane. At the higher initial level of 26 ppm, a corresponding decrease five times as great, or of about 10 ppm, may be anticipated.

TABLE 4. EFFECT OF CROPPING ON THE LEVEL OF SOIL PHOSPHORUS WITHOUT THE ADDITION OF PHOSPHATE

Plantation	Expt. No.	Field	Phosphorus		
			Initially	After 1 Crop (2 years)	Difference
			ppm	ppm	ppm
McBryde.....	90c AN × P × K	19C	45	29	-16
Paauhau.....	107 (a) AP × K	18	44	40	- 4
Lihue.....	366 AP × K	20M	43	35	- 8
Paauhau.....	107 (b) AP × K	22E	42	37	- 5
Olaa.....	101 (a) AP × Ca	7	42	27	-15
Lihue.....	319 AP × K	7M	38	30	- 8
McBryde.....	80 AN × P × K	14A	38	37	- 1
Paauhau.....	95 Res. A × FP	20	35	32	- 3
Grove Farm.....	125 AN × P × K	H-4A	32	29	- 3
Kilauea.....	265 AN × P × K	28	28	24	- 4
Olaa.....	109 (a) AP × Ca	4 & 5	26	23	- 3
Pepeekeo.....	83 AP × Ca	9	26	17	- 9
Kilauea.....	264 AN × P × K	10	24	13	-11
Hakalau.....	119 A × FP	123-2	22	15	- 7
Laupahoehoe.....	32 A × TP	A-2	22	12	-10
Lihue.....	322 AP × K	30 Hm	22	8	-14
Pepeekeo.....	68 AP × K	88A	20	15	- 5
Hakalau.....	118 AP × Ca	134-1	19	14	- 5
Lihue.....	307 AP × K	5 Hm	19	13	- 6
Pepeekeo.....	88 A × FP	69	18	17	- 1
Honokaa.....	70 AP	18	17	13	- 4
Laupahoehoe.....	31 AP × K	M 68	17	15	- 2
Lihue.....	354 AP × K	18L	16	13	- 3
Grove Farm.....	122 AP	K 37	15	10	- 5
Lihue.....	351 AP × K	20 A Hm	15	13	- 2
Lihue.....	359 AP × K	Mi 1M	14	9	- 5
Lihue.....	360 AP × K	9 Hm	14	16	+ 2
Pepeekeo.....	82 A × FP	86A	14	11	- 3
Lihue.....	324 AP × K	1A-M	13	5	- 8
Lihue.....	365 AP × K	15 Hm	13	9	- 4
Laupahoehoe.....	36 A × FP	P-49	12	12	0
Lihue.....	339 AP × K	33 Hm	12	11	- 1
Kilauea.....	263 A × FP	1	9	6	- 3
Ave.					-5.6

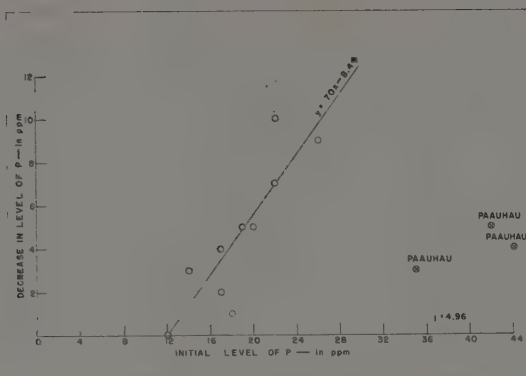


Figure 4

With the three Paauhau experiments, shown at the extreme right in the figure, decreases in phosphorus on cropping are very small considering the relatively high initial levels of the element.

### Potassium

In the absence of added potash, the supply of soil potassium also appears to be lowered by cropping and at a more rapid rate than in the case of phosphorus. This is evidenced in Figure 5, where initial supplies of potassium are plotted against corresponding decreases for all available "amounts of potash" tests, except those on physically abnormal soils.

As with phosphorus, the extent to which the level of potassium is lowered appears to be a function of the supply of the element initially present. This relationship, which is significant beyond the .01 level, is indicated in Figure 5 by a straight line. Reference to the figure indicates that on the average, at the critically low level of 50 ppm K, the decrease with cropping is only about 10 ppm. At the high value of 200 ppm, the resulting decrease is in the vicinity of 80 ppm. Corresponding differential decreases have been observed in pot studies with Hawaiian sugar cane soils in which indicator crops were grown in the absence of added potash (2).

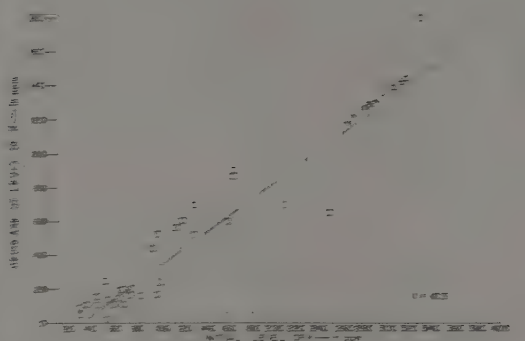
In a considerable proportion of the tests represented in Figure 5, crops of normal size were obtained, no response having been shown to potash fertilization. In these tests, and even in those where response was in evidence, the quantities of potassium taken up must have far exceeded the corresponding decreases in supplies of soil potassium. This testifies to the great economic importance of the reserves of potassium in Hawaiian soils, as well as to the rates of their release to available forms. It also abundantly supports the results of earlier studies of the subject in Hawaii with crops other than sugar cane (2, 4).

### SOIL ANALYSIS IN RELATION TO FIELD EXPERIMENTS

Field experiments and soil analysis go hand in hand. Field tests give meaning to analysis for the purpose of establishing fertility levels, while analysis does much to enhance the usefulness of field tests.

The value of a field experiment is greatly enhanced by a knowledge of the

Figure 2



nutrient status of the soil in the experimental area. The results of the test are thus not limited to the particular soil, but, to a degree, apply to other soils of similar nutrient level.

Where critical levels have been fairly established soil analysis can be employed to determine whether or not there is a need for the test in question. Little is gained by conducting an "amount of nutrient" experiment where the supply of the element is safely above the critical level.

Soil analysis may also be employed to advantage in the selection of areas of comparative fertility for the controlled group tests. Results for the group as a whole are of limited value when component tests are conducted on soils which range from a condition of deficiency to one of abundance with respect to the variable element, unless through adequate replication each member is sufficient within itself.

The variability in nutrient content of the soil at the site proposed for an experiment can be determined quickly and inexpensively by soil analysis. Even when it is deemed advisable to conduct a test on a variable area, knowledge of the pattern of variation may be useful in the subsequent interpretation of field data.

Results of many "factors of nutrient" experiments, both here and elsewhere, are misleading because the soils on which they were conducted were already adequate, superior or deficient with respect to the element in question. Such costly mistakes can be avoided by soil analysis.

In field experiments, optimum response to the variable element can result only when non-variable elements are present in adequate supply. Soil analysis provides a means for detecting and correcting such deficiencies.

## SAMPLING SUGAR CANE SOILS

The areas ready for use for sampling sugar cane soils for chemical analysis require no further work, after seedbed preparation has been completed. At this stage any residue of fertilizer remaining in the cane lines at the end of the final work in the field is likely to be more or less mixed with the tilled layer of soil. Moreover, any incorporation of nutrient-deficient subsoils into this layer as a result of deep plowing is complete for the coming cycle. At this time also, soil samples may

be secured with the least expenditure of time and effort and with a maximum of observation regarding physical variability.

Sampling in ratoon fields is generally restricted to the inter-row. Since root activity is greatest in the immediate vicinity of the line, samples are often taken as close to the line as due regard for possible "contamination" by residues of fertilizer applied to preceding crops will permit. How close to the line such sampling may approach depends, in a degree, upon the method of fertilization employed on the particular plantation.

Sampling directly in the cane line at the end of plant and ratoon crops, for the purpose of supplementing data obtained from samples taken in the inter-row, is in the experimental stage. Data pertaining to the line is valuable, at least in a qualitative sense, in that it indicates the presence or absence of residues from the line fertilization of preceding crops in the cycle.

Little has been done in this connection thus far, except in relation to phosphorus. Within limits, samples taken in the line have been found to reflect the amount of phosphate applied. As would be expected, however, results are generally very erratic. They are also difficult of interpretation on a quantitative basis since the volume of soil represented by the sample is unknown. The problem is particularly complex where either rock phosphate or so-called "under-acidulated rock phosphate" has been used. Under such conditions, results for phosphorus are often much higher than where equivalent amounts of soluble phosphates have been employed (7). Experience has shown that when localized, rock phosphate is not quickly dissolved and adsorbed by the soil.

Soil sampling, except for special purposes, should have as its aim the obtaining of a sample representative of the zone containing the bulk of the cane roots. Where plowing is normally deep, this corresponds roughly to the tilled layer. Where tillage is unusually deep, samples representing the surface foot of soil should suffice. Where shallow tillage is practiced, it may be desirable to obtain samples of the upper few inches of undisturbed subsoil, as well as samples representing the tilled layer. Subsoils in a given area often differ but little in fertility, and a few such samples may serve to characterize this portion of the root zone. In sampling plowed fields, allowance should be made for temporarily low volume-weight, the depth of sampling corresponding to the appropriate depth of soil in the settled condition.

Some plantation soils are quite variable in nutrient content, although others are not. The greatest variations appear to occur on the dissected and eroded phases of several soil families where, in places, what formerly were subsoils are now being cultivated as surface soils. This factor of variation largely governs the number of soil samples that should be taken per unit area. In assessing variability for a particular plantation or soil type, it is well, initially at least, to sample freely, using the results thus obtained as a guide to future operations.

Ordinarily it is desirable to take a sample, made up of 10 to 12 subsamples, for each 10 acres of land. Over-compositing should be discouraged. A single sample composed of 50 subsamples and representing 50 acres does not furnish the information concerning variability and reliability given by five samples, each consisting of 10 subsamples. Yet the labor involved in one case is about as great as in the other.

The universal practice of compositing soil samples indicates a realization of

TABLE 5. VERTICAL DISTRIBUTION OF PHOSPHORUS IN LIHUE SOILS

Expt. & Field Nos.	Depth	Phos- phorus	Expt. & Field Nos.	Depth	Phos- phorus	Expt. & Field Nos.	Depth	Phos- phorus
	in.	ppm		in.	ppm		in.	ppm
339 AP × K	0-3	15	351 AP × K	0-3	13	354 AP × K	0-3	10
33 Hm	3-6	9	20A-Hm	3-6	8	18 L	3-6	7
	6-9	5		6-9	6		6-9	4
	9-12	3		9-12	4		9-12	2
	12-15	3		12-15	4		12-15	1
	15-18	3		15-18	4		15-18	2

the fact that the nutrient content of the soil may vary substantially even within small areas. It is less generally appreciated that it may also vary considerably with depth. However, variations with depth display more semblance of order than lateral changes (3, 5, 6). These points are illustrated by the results, shown in Table 5, from a recent profile study of phosphorus in the zero P plots of several Lihue experiments. The samples were taken a few months after the crops were ratooned.

The effect of depth of sampling upon the phosphorus content of the sample is seen to be very marked.

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## DISCUSSION

**H. F. Clements:** It seems to me that I'm doing all the talking this time, but I hope we don't have another seminar for about 10 years. On this soil analysis business, I must confess that a plant physiologist looks at the problem quite differently from a soil chemist. In other words, when we talk about the Truog phosphate which, of course, isn't a new development, the paper having been published in 1930, we certainly are trying only to imitate the process which the plant employs in extracting nutrients from the soil. Now, obviously, one of the biggest factors affecting the ability of the plant to extract nutrients from the soil on the one hand, is the state of that nutrient, and on the other hand, is the position of the roots, and vigor of that plant. Now, I'm going to give you some cases here where there has been rather a serious departure from the predicted and, again, I don't want this misunderstood, Arthur. I hope to goodness you keep on with this sort of thing. I think we need a great deal of that. But when it comes to predicting whether or not the plant is going to get enough stuff out of the soil, I think we're on rather shaky ground, and I think the evidence is developing in a rather clear-cut fashion. Let us just say that we have a correlation of .8, or something like that, between the soil phosphorus and the actual results. On the basis of accounting for a variation, we are only predicting about 64 per cent of our cases, which means we are missing around 36 per cent. When a soils man goes out and samples soils, he may take a shovel or he may take a borer, and bore down and take a sample. Now, compare that with what the plant does. The plant is growing in this soil; its roots are spread through five feet—2.5 feet, say, on each side of the line—and while I know that again we would disagree here on the depth of the roots, yet we do find them going down pretty far. So, the plant is actually a much better sampler of the soil than is the man who goes out with a shovel or a hoe to sample that soil. Now, the Truog method uses the sulphuric acid extraction. Now, one thing we're very sure of is that the plant does not use sulphuric acid as an extracting medium. In other words, we're only trying to imitate what the plant does. Now, the other thing is this: we're not recognizing, we're not giving recognition to the tremendous principles which were laid down by Hoagland at Berkeley, that in absorption from the soil of nutrients, the plant exerts energy. In other words, if that plant is living in a fairly happy medium as far as oxygen is concerned, it will probably do very much better, and if a carbohydrate supply is available, it will probably do very much better than if it is somewhat restricted in those things. In other words, the plant is being ignored, even in sugar cane. Now mind you, differences have already been reported in other crops. Incidentally, Truog has several papers showing the very large number of discrepancies from the predicted. He also used 20 ppm for most of their crops. He actually developed other methods based on the growth of fungi that come into the picture. Now, let me just give you a few of the cases in point. Here, for example, is a variety test that is being conducted at Kilauea Sugar Plantation. Now, these varieties were all treated the same—this is a Grade A test—in which we have three varieties: 1933, 3098 and 3633. Now, the phosphorus level for a few of these figures are like this: on the same date, mind you—.093, .078, .085 and .086. I should have brought the potassium figures, too, because the potassium figures on the 1933 showed a deficiency. Now, on the 3098: 1.25, 1.46, 1.13, 0.97 and 1.07. On the 3633: 1.08, 1.29, 1.13, 1.03 and 1.08. In other words, we have quite a difference here in the abilities of the various varieties in extracting phosphorus. Now, I would certainly be willing to wager that your soil analysis, since this is a standard replicated Grade A test, would average out the same for those three varieties. Needless to say, in this particular test, I think more because of the potash, 1933 lost out in this Grade A test. In other words, it wasn't adequately supplied with nutrients.

**Dr. Gortner:** I'd like to ask Dr. Ayres whether the analyses can offer a means of getting at this reserve of nutrients which you indicated as perhaps accounting for 80 per cent of what is taken up by the crop. Certainly with continuous cropping on the land, we stand a chance of depleting these reserves so that while your analysis might indicate what is immediately available, it is equally important to determine what is the status as far as future crops are concerned.

**A. S. Ayres:** A good deal of that sort of thing has been done in the case of potassium. We have studied the release of potassium very extensively here in the Islands, and of course, there have been extensive studies elsewhere. It's a long-winded procedure, to do it biologically. Some people have extracted soils with strong acid, and we have done that also. It gives a sort of a relationship with results which we have gotten where we have measured this reserve by cropping. It can be done; whether it's worth while or not, I don't know. There was some indication in our work that there is a relationship between the rate of release of potassium and the level of exchangeable potassium.

**R. P. Humbert:** I'd like to comment further on the potash reserves in the soil. The point has been mentioned previously of the shipments of potassium that have been going out in our molasses. Calculations have been made for a number of plantations using the average percentage potassium composition of their molasses, and compared against the potash purchases in fertilizer. In one instance I recall where a plantation had a net loss of over 2500 tons of  $K_2O$  in a period of seven years. So, this question of reserve in the soil, which Arthur tells me runs anywhere from 10 to 40 thousand pounds of  $K_2O$  per acre foot, is a very serious one.

**Philip Conrad:** On that particular point, we might forget about the amount of potash that we are pumping in our pump water. We are quite high, and with an irrigation we put on somewhere around 25 pounds.

**L. D. Bayer:** That's very important to quite a few of the irrigated plantations.

**R. Toyofuku:** I believe yesterday Dr. Ayres suggested that plantations should work their phosphate into their soil rather than apply it in a band. I think this morning Dr. Burr also mentioned that in the phosphorus curve, if the fertilizer is applied in a band, then in the early part of the crop the plant takes up the phosphorus, but at six, seven and eight months of age, there is a drop in the per cent phosphorus. Then at 16 to 18 months, the curve rises again. I wonder if, in our experiments, our present methods of applying the phosphorus with the seed in bands is the wrong approach to what we are looking for.

**L. D. Bayer:** I don't think Dr. Burr suggested that plantations change their practice of putting it in bands. He was just making a remark relative to the type of data he was getting—that is, if you could have your phosphorus well distributed, you're going to get a whole lot more efficiency than if you put it in a band. In order to keep from having it locked up in the soil, you need to put it in a band or else you need a whole lot in the soil. So, with most of your phosphate application, you have to localize it more or less in spite of the fact that if it were equally distributed throughout the soil, you would have a better proposition, as far as phosphorus is concerned. Isn't that the way you interpret it?

**R. P. Humbert:** We'll have some more data on this subject in the next paper.



## FIELD EXPERIMENTATION TO CORRELATE SOIL AND PLANT ANALYSIS WITH YIELDS OF CANE AND SUGAR

ROGER P. HUMBERT\*

In 1897, the first of a long series of field experiments in the Hawaiian sugar industry was installed by C. F. Eckart. The first cooperative plantation field experiments in fertilization were started in 1904. From this date, field experiments have played a very important role in establishing plantation practices and have been supplemented by many programs, such as RCM, crop logging, and refinements in soil and plant analyses as presented in this seminar.

Increasing maintenance costs of the extensive field testing programs have in the last few years stimulated efforts to increase the effectiveness of control procedures in soil and plant analyses. The results of these studies as indices of nutrient availability were presented by Burr (2) and by Ayres and Hagihara (1). Working with only one plant, critical levels in various parts of the plant or in the soil are more easily established than with a multicrop agriculture.

Sugar cane in Hawaii is grown under a variety of soil and climatic conditions, and no matter how much effort is expended to characterize a given soil and climate, modifications will be required in the management of the adjacent field. It may have shallower surface soil or a cloud cover during a much larger portion of the daylight hours.

Realizing these difficulties, the agronomic research pattern has been set to characterize as completely as possible the soil factors which affect the growth of plants—the supplies of water, oxygen and of plant nutrients, all of which are related to the depth and character of the soil. The depth of soil in which plant roots develop may be altered by drainage where a water table limits root development, or by deeper plowing to mix into the tilled layer some of the underlying subsoils. This mixture of surface soils and subsoils often requires special treatment to insure a satisfactory seed bed, particularly where phosphate in the subsoil is critically low.

### CONTROL OF PHOSPHATE FERTILIZATION

It has been found necessary to adjust the phosphorus readings for rocky and shallow soils in order to correlate favorably with yield data based on normal soils. At Olaa Sugar Company, response to phosphate fertilizers was observed where the level of available phosphorus in the soil was 45 ppm. The soil had been screened prior to analysis and it contained 50 per cent rock. This reduction in

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effective volume of soil lowered the level of available phosphorus to near the presently-accepted critical level.

Soil analyses should give an accurate indication of the reserves of soil nutrients available to the cane plant. Soil analyses are now being used to guide the phosphate and calcium fertilization programs. Since Hawaiian soils in general have the capacity to effectively fix phosphorus, and since phosphorus plays such an important role in early root and shoot development, it is of paramount importance to establish the phosphate requirements at the start of a crop. Excesses applied are not lost through leaching, but are retained for subsequent crops.

Ayres and Hagihara (1) have presented the relationship between the results of field tests and levels of available soil phosphorus. The critical levels thus established have proved reasonably effective in guiding phosphate fertilization on thousands of acres of cane land and in reducing the number of phosphate experiments where the level of available phosphorus in the principal soils has become known.

### RADIOACTIVE PHOSPHATE FERTILIZER EXPERIMENTS

New tools were used to help establish the critical level of available phosphorus in the soil. Six experiments, harvested in 1954, used radioactive phosphate fertilizers\* for the purpose of testing phosphorus nutrition near the established critical level. Two nine-foot sections of line in each 1/20-acre plot of the experiments received the radioactive phosphate fertilizer, while the remainder received the same kind and amount of ordinary fertilizer. The sub-plots receiving the radioactive fertilizer were harvested at 90 to 100 days. Yield data are presented in Figure 1. At Laupahoehoe, Hakalau and Onomea, where levels of available soil

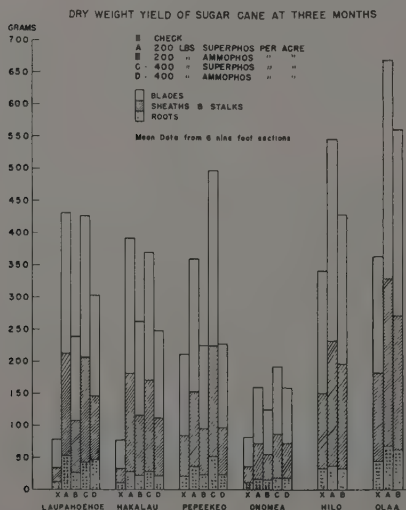


Figure 1. Yields from six radioactive phosphate fertilizer experiments, comparing superphosphate and ammophosphate at 200 and 400 pounds  $P_2O_5$  per acre, where soils were deficient in available P, and at 200 pounds per acre where adequately supplied with P.

\* The radioactive phosphate fertilizers were produced by USDA Plant Industry Station, Beltsville, Maryland. These experiments were cooperative experiments between the Departments of Agronomy and Physiology and Biochemistry and Laupahoehoe, Hakalau, Pepeekeo, Onomea, Hilo and Olaa plantations.

# PHOSPHORUS ANALYSIS OF SUGAR CANE IN P-32 EXPERIMENTS

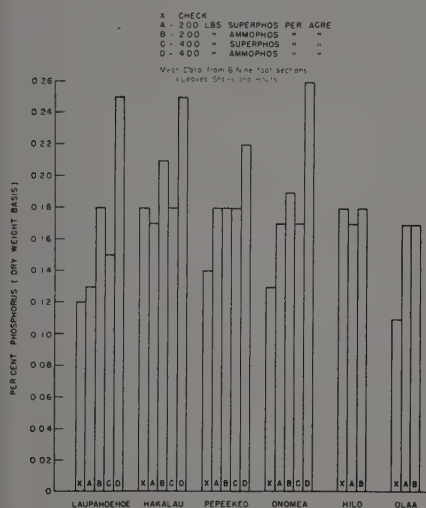
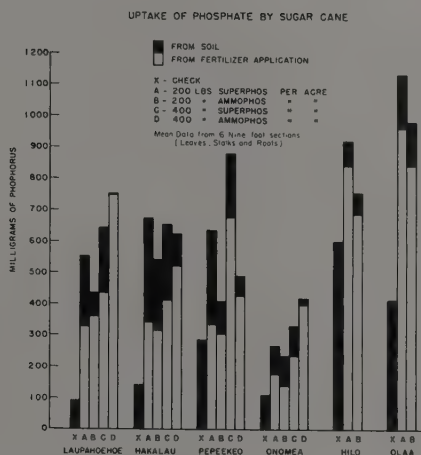


Figure 3. Utilization of available soil phosphorus and fertilizer phosphorus supplied at 200 and 400 pounds  $P_2O_5$  per acre where the soils were deficient in available phosphorus and at 200 pounds per acre where adequately supplied with P.

Figure 2. Phosphorus analyses of sugar cane at three months of age in the radioactive phosphate fertilizer experiments.



phosphorus were below 20 ppm, yields of the check plots are significantly lower than at Hilo and Olaa where the levels were higher. In all experiments, the yields of the superphosphate plots at the age of three months were greater than of the ammophosphate plots. Figure 2 shows the phosphorus content of the cane at the three-month harvest. The levels of phosphorus are high, even in the check plots. It is of interest to note the luxury consumption of phosphorus from ammophosphate. Phosphorus was absorbed in early growth but not utilized, possibly because of a shortage of calcium. The amounts of phosphorus obtained from the soil and from the fertilizer in all experiments are presented in Figure 3. A significantly larger percentage of phosphorus comes from the soil in the superphosphate plots than in the ammophosphate plots. This is possibly explained on the basis that the root systems in the superphosphate plots were much better developed than those in the ammophosphate plots, and extended into larger volumes of soil.

The harvest results of Group Test No. 14 are listed in Table 1. They show fairly consistent gains for phosphate fertilization at or below the established critical level of available soil phosphorus.

TABLE 1. HARVEST RESULTS OF RADIOACTIVE PHOSPHATE FERTILIZER TESTS  
(Group Test No. 14)

		TCA	Y% C	TSA			TCA	Y% C	TSA
Hakalau Expt. 124 A X FP Available Soil P 11 ppm, pH 4.9	0# P <sub>2</sub> O <sub>5</sub> 200 400 LSD	102.8 105.9 107.8 ns	10.7 10.7 10.8 ns	11.0 11.3 11.7 ns	Laupahoehoe Expt. 36 A X FP Available Soil P, 12 ppm pH 5.0	0# P <sub>2</sub> O <sub>5</sub> 200 400 LSD	81.7 88.8 92.2 ns	11.3 11.9 12.0 ns	9.1 10.6 11.0 1.1
Forms of P	Superphos Ammophos LSD	113.1 100.6 10.4	10.5 11.0 ns	11.9 11.0 ns	Forms of P	Superphos Ammophos LSD	95.7 85.3 9.7	11.7 12.2 ns	11.2 10.4 ns
Onomea Expt. 71 A X FP Available soil P 14 ppm, pH 5.2	0# P <sub>2</sub> O <sub>5</sub> 200 400 LSD	91.3 106.7 104.5 ns	10.1 10.0 10.3 ns	9.1 10.7 10.8 ns	Peepee Expt. 88 A X FP Available Soil P, 17 ppm pH 5.3	0# P <sub>2</sub> O <sub>5</sub> 200 400 LSD	83.6 82.2 84.4 ns	10.6 10.2 10.5 ns	8.8 8.4 8.8 ns
Forms of P	Superphos Ammophos LSD	111.2 100.0 ns	9.9 10.4 ns	11.1 10.4 ns	Forms of P	Superphos Ammophos LSD	82.7 83.9 ns	10.2 10.5 ns	8.4 8.8 .4
Hilo Sugar Expt. 148 A X FP Available soil P 21 ppm, pH 5.3	0# P <sub>2</sub> O <sub>5</sub> 200# LSD	75.1 91.1 9.8	11.3 10.4 .6	8.5 9.5 ns	Olas Expt. 108 A X FP Available Soil P 30 ppm (soils 35% rock) pH 5.3	0# P <sub>2</sub> O <sub>5</sub> 200# LSD	56.5 72.7 9.0	13.1 13.4 ns	7.4 9.7 1.2
Forms of P	Superphos Ammophos LSD	94.9 87.3 ns	10.5 10.3 ns	9.9 9.0 ns	Forms of P	Superphos Ammophos LSD	71.3 74.0 ns	13.0 13.8 ns	9.3 10.2 ns

#### SUMMARY OF AVERAGE YIELDS

Lbs. P <sub>2</sub> O <sub>5</sub>	(N)	TCA	Y% C	TSA
X = 0.....	12	89.9	10.7	9.5
A & B = 200.....	24	95.9	10.7	10.2
C & D = 400.....	24	97.2	10.9	10.5
LSD 12 vs. 24		5.7	ns	.6
24 vs. 24		4.7	ns	.5
Forms of P <sub>2</sub> O <sub>5</sub> (n = 24)				
Superphos.....		100.7	10.6	10.6
Ammophos.....		92.4	11.0	10.1
LSD	4.7	.4	ns	

### CONTROL OF POTASH FERTILIZATION

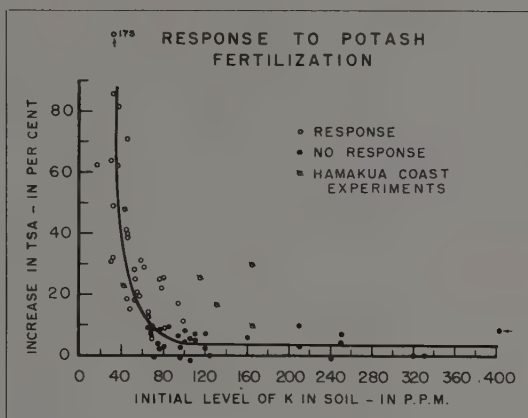
Response to potash fertilization at different initial levels of soil potassium is shown in Figure 4. The data show generally marked gains as the soil potassium level falls much below 100 ppm. Above 100 ppm, significant responses to potash are rarely obtained. The only exceptions are found in the low volume-weight soils where, for a given level of potassium expressed in ppm, the amount of potassium per acre foot is considerably lower than in the high volume-weight soils for which the critical level was initially established.

Once the critical levels have been established by correlation with field yield data, the number of experiments can and should be drastically reduced. At very high levels of exchangeable soil potassium, it is useless to test for potash response. Testing is not warranted until the point is reached where decreases in yield or recovery of sugar may be expected.

Testing for response to potash fertilization at very low levels of soil potassium is also unnecessary. Since response is assured, the only factor that needs to be resolved is the optimum level of potash to be applied. Soil data can be used to control early fertilization and to insure against deficiencies in the first few months of growth. As soon as the cane is large enough to be sampled, leaf sheath or stalk potassium will give a good guide to subsequent potash fertilizer requirements.

Plant analyses show what a plant is able to obtain from a given soil under a given set of climatic conditions. Critical levels, once established, should provide a useful basis upon which to calculate the supplementary plant food requirements late in the first season and throughout the second season's growth. This is par-

Figure 4



ticularly true of nitrogen and potash which are now universally applied in split applications.

In Group Test No. 11, on the American Factors plantations and Olokele Sugar Company, the six to 10 months' sampling period was shown to be the most highly correlated with TSA at 24 months. In samples taken after 10 months of age, there was an almost linear decrease in the correlation with age. These data emphasize that the time to calculate the second season's fertilizer requirements is near the end of the first season's growth. This timing after lodging of the primary stalks permits an examination of the reserves left to grow and mature the secondaries and suckers in the second season. The above conclusions are supported only by data from the spring plantings. Analyses of the fall plantings and subsequent ratoons are expected to confirm or alter these conclusions.

Yield data and leaf sheath potassium curves for Lihue's Experiment 329 AN  $\times$  K are presented in Figure 5. In the check plots, the levels of sheath potassium were critically low throughout the history of the crop. Yield response in both cane and sugar was obtained with potash fertilization which raised the levels of potassium in the plant. In more recent experiments, as other limiting factors of growth were eliminated, response has been obtained for higher rates

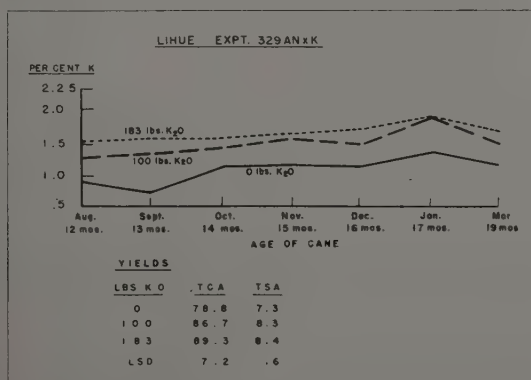


Figure 5

of potash fertilization. In these experiments, levels of sheath potassium in the fertilized plots were maintained close to two per cent.

A summary of Grade A fertilizer experiments is presented in Table 2. The experiments are grouped into three five-year periods. The total number of each type of experiment is listed for each sugar-producing island together with the number of experiments that show statistically significant differences in yields of cane per acre, juice quality, or sugar per acre.

TABLE 2. SUMMARY OF GRADE A FERTILIZER EXPERIMENTS FOR 1940-1954

AMOUNTS OF NITROGEN EXPERIMENTS											
1940-44				1945-49				1950-54			
No. Expts.	TCA	Y% C	TSA	No. Expts.	TCA	Y% C	TSA	No. Expts.	TCA	Y% C	TSA
Hawaii.....	105	60	-34	-2	40	22	-10	13	84	29	-9
Maui.....	35	18	-13	16	3	1	0	0	10	5	+2
Oahu.....	33	13	-11	-3	19	5	-4	2	35	12	-6
			+5								11
Kauai.....	83	48	-35	-2	30	12	-13	5	107	54	-27
			+3								+33
TOTAL.....	256	139	-93	-7	92	40	-27	20	236	100	-42
			+5				+1				+75
Per cent Response			-36.3	-2.7			-29.3				-17.8
	54.3	2.0	32.8		43.5	1.1	21.7		42.4	2.5	31.8
AMOUNTS OF PHOSPHATE EXPERIMENTS											
Hawaii.....	44	9	2	7	21	7	3	3	41	19	7
Maui.....	28	1	2	1	..	..	..	..	..	..	..
Oahu.....	19	2	2	2	1	0	0	0	12	0	0
Kauai.....	92	8	8	10	32	3	3	3	64	13	8
TOTAL.....	183	20	14	20	54	10	6	6	117	32	15
Per cent Response		10.9	7.7	10.9		18.5	11.1	11.1		27.4	12.8
											26.5
AMOUNTS OF POTASH EXPERIMENTS											
Hawaii.....	66	30	-2	29	26	7	3	4	47	20	-2
Maui.....	30	7	+10	8	..	..	..	..	6	1	+5
			-1								0
Oahu.....	38	-1	+4	7	8	2	-1	1	31	6	0
			7								5
Kauai.....	66	+6	7	-1	29	9	-1	7	85	42	-4
		27	-4								-2
			+8								+14
TOTAL.....	200	-70	-7	-1	63	18	-2	12	169	69	-6
		29	72			30				19	+2
Per cent Response		-0.5	-3.5	-0.5		28.6	-3.2	19.0		40.8	-3.6
		35.0	14.5	36.0			4.8			11.2	-1.2
											-0.4

In the amounts of nitrogen experiments, the percentage of tests that showed significantly poorer juice quality was considerably lower for the 1950-54 period than for the two preceding five-year periods. This is attributed largely to the elimination of potassium, phosphorus and calcium as limiting factors of growth, thus permitting more effective utilization of the larger amounts of nitrogen applied. The average yearly fertilizer purchases for the Hawaiian sugar industry in the three five-year periods were as follows:

	1940-44	1945-49	1950-54
Tons N.....	10,854	10,131	13,183
Tons P <sub>2</sub> O <sub>5</sub> .....	4,015	3,944	6,315
Tons K <sub>2</sub> O.....	8,683	8,290	13,027

In the amounts-of-phosphate experiments, a very low percentage of tests showed significant gains in TCA or TSA in the first two five-year periods. Soils in general were still supplied with reserves of phosphate built up during the middle 1930's when excessive amounts of phosphate fertilizer were applied. The percentage of tests that gave significant differences in yield for phosphate applications rose sharply in the 1950-54 period. By this time, the soils' reserves in many areas,

particularly in the wetter windward unirrigated plantations, were depleted. Soil tests were responsible for rejecting for phosphate experiments those sites in which supplies of available soil phosphorus were far above the critical level. As the critical levels in soil and plant analyses become established, fewer field experiments will be required.

In the amounts-of-potash tests, 40 per cent of the experiments showed significant gains for potash fertilization. Gains in tons sugar per acre ranged from less than one to over three tons. Field experiments and soil and plant analyses have been responsible for the marked increase in rates of potash fertilization in recent years.

Field experiments have been shown to be invaluable in establishing critical levels in the soil and in the plant. After these critical levels have been adequately checked in field trials, soil and plant analyses should minimize the effort now expended in harvesting field fertilizer experiments. Factorial experiments with new promising varieties and tests checking critical levels of other limiting factors of growth will continue to be necessary in the future. A fewer number of tests will result in gaining more supplementary data to aid in the interpretation of the test results so that the data can be used over a larger area and for specific sets of soil and environmental conditions.

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## DISCUSSION

**W. W. G. Moir:** I would like to say just a word in regard to the interrelationship of nitrogen and phosphorus and potassium. It is a question of the effect of the application of one on the other. Most of the data from the Amfac coordinated set of experiments show that interrelationship in a clear way, but influenced also by the effect of time of year and the pattern of life of the cane plant so far in our experimentation. That time of year effect has a tremendous influence on whether nitrogen decreases phosphate or potash or whether it carries them on at the same level, and I think we should have a great deal more thought given to experiments that will be economically handled and will give the answers to these combination-of-fertilizer and time-of-year factors.

**R. P. Humbert:** Certainly, by reducing the numbers of experiments that we have, we will be able to put forth more effort on some of the experiments and will be able to arrive at answers that can be translated into larger areas. For example, we have to gain a lot of supplementary information to permit the interpretation of the data to make possible the use of that data over a larger area. The experience that we have gained in these  $3 \times 3 \times 3$  experiments with age of harvest  $\times$  amounts of nitrogen  $\times$  amounts of potash started at two times of the year, certainly emphasize the importance of specialization in using fewer experiments to arrive at an understanding of the interaction of some of the factors of growth.

**L. D. Bayer:** I'll comment on that, if I may. You must remember that these analyses, either plant or soil, are tools to be used with judgment in handling the particular field you are farming. I think everybody recognizes that. But it is important, especially when you're thinking in terms of fertility analyses, be they soil or plant, if anything else than fertility is a limiting factor, then you have to use your head, so to speak, as you interpret the analyses you get.

**W. W. G. Moir:** I would like to mention the fact that as you get more of these cooperative tests and less of a lot of these that are thrown in, we'll get the answers to our story a lot quicker. Again, in some of this work, the response is very, very different in one place at one time of year than it is in another, and those factors all have to be worked out. Our data show both the crop logging by Clements' method and by Burr's method gave very different results for different times of the year, and the thing that really impresses you most is the long period over which you can really know what you're getting out of Burr's approach as compared to the short period after which you can't get an answer to your story any further by the Clements method. It stops at 12 months in our experiment and carries on until 18 or more by the Burr method.

**R. O. Smith:** I don't know if this will enlighten anybody, but I remember years ago there was a lot of work done here in using Mitscherlich pot studies to determine plant food requirements. There has been nothing said about it, but there is one thing there that has always bothered me. They had shown, in growing tomatoes, that if you put on a very large quantity of phosphate, there was a phenomenal increase. . . .

**L. D. Bayer:** With respect to Mitscherlich work here, that was discontinued about five or six years ago when we started substituting plant analysis to get at some of the same problems.

## DEVELOPMENT OF AND EXPERIENCES WITH CROP-LOGGING IN HAWAII\*

HARRY F. CLEMENTS\*\*

Crop-logging on most Hawaiian sugar plantations has in the course of the last ten years become standard procedure. It has been taken up by many foreign countries which produce sugar. It is being used either experimentally or in production in the Philippines, Formosa, India, South Africa, Peru, Venezuela, the British West Indies, Puerto Rico, Panama, the Dominican Republic, and perhaps others. I thought in this paper it might be of interest to set down some of the routes which were traversed in the development of this system, and to append to it a complete list of my papers dealing with sugar cane and crop-logging.

The early beginnings of crop-logging actually go back to my days as an instructor at Michigan State College from 1925-28. The two summers I spent at East Lansing were spent in following the growth and composition of three field grown crops—potatoes, sunflowers and soy beans. Collections were made regularly throughout the crop and on a few occasions collections of leaves were made every hour for twenty-four hours. These plants were analyzed for several soluble and insoluble nitrogen and carbohydrate fractions. The papers dealing with this work have all been published.

In 1928 I left East Lansing and went to the University of Chicago to complete my graduate work toward the doctorate. Here I studied in the Botany Department, and in addition to work in physiology, morphology, plant anatomy, pathology, etc., I took quite a bit of work in plant ecology. It was my good fortune to study under Dr. H. C. Cowles whose original concepts on physiographic ecology were most stimulating to me—the essential idea here is that the plant not only adapts itself to fit into its environment but by its presence modifies the environment—and most important in determining plant success, the physiographic factors of temperature, light, wind, exposure and especially moisture far outweigh soil factors such as chemical composition. This teaching was really in sharp contrast to what I had received in my undergraduate days in courses which I took in soils, agronomy, horticulture, in addition to considerable work in agricultural and organic chemistry.

The concept that soils and soil fertility produce crops is of course in direct conflict with the idea that crops are produced as a result of the energy available to them tempered and modified by the moisture and nutrient status of the plant in

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relation to its environment. The nature of this conflict became much clearer to me at Washington State College where, from 1929 to 1937, I carried on a research program in addition to teaching not only beginning botany, but several courses in plant physiology, plant ecology and plant anatomy. During my plant ecology teaching, each Saturday was spent on a field trip with my class, sometimes into the mountains, sometimes into the desert, studying natural vegetation and the factors affecting its distribution. Although the soils in that country are very fertile, the plants growing on them were the highest types which the temperature and moisture of the region could support and varied enormously from one moisture condition to another from sagebrush to bunch grass prairies to cool moist forests. And so it was, on Tuesday, Thursday and Saturday, I taught what was obvious to me as a plant ecologist. On Monday and Wednesday, however, I taught a course in mineral nutrition for graduate students in the various agricultural departments. And, of course, on these days, I taught what was obvious to me as an undergraduate major in agronomy—that soil fertility is everything. Now I must confess as time went on the conflict of these concepts intensified within me, but fortunately students in agriculture didn't take my course in ecology and students in botany generally didn't take the course which attracted the agricultural students.

While I was at Pullman, I carried on a research project dealing with a study of the mechanism which Douglas fir and yellow pine use in resisting freezing temperatures. I went up a small isolated butte about a thousand feet above the surrounding country once each month to collect samples of leaves and branches. These were analyzed for the various nitrogen fractions, soluble and insoluble, as well as carbohydrates and the ether extracts. As the trees in their natural state adjusted themselves on the one hand to the coming of winter and its severe cold and on the other hand to the hot summer with its drought certainly I was impressed with their adaptive potentialities. Also, on these trips, I always had some students with me and we used to discuss all these things. While I must have confused many of them, I think at least I was developing a working concept.

And so it was one blizzardy day in February of 1937, not long after one of these trips, that a letter came from Dr. Harold St. John of the University of Hawaii's Botany Department inviting me to come to Hawaii as an Associate Professor of Botany. In reading about Hawaii, I decided that if I had a chance I would certainly want to study plant growth under the different weather conditions which prevailed here. The opportunity presented itself within a year after my arrival. Dr. David L. Crawford, President of the University, offered me the opportunity to organize the Department of Plant Physiology at the University's Experiment Station—a connection which I cherish to this day. The late Dr. Oscar Magistad stayed long enough to set the new department up in the budget and then he left as Director. So, on July 1, 1938, I was Head of the Department with one staff member, Ernest Akamine, and one project, Dormancy of Seeds. After discussing other possible projects with Acting Director Henke and Dr. J. H. Beaumont, who was to be the new Director, I asked if I might approach Dr. Harold Lyon of the Sugar Station to work on sugar cane. It seems there had been a sort of unwritten law that University people not work on pineapples or on sugar cane, but Dr. Lyon, who with Mrs. Lyon had been very kind to my wife and to me, listened patiently and when I had finished outlining my project, he said, "I'll answer you in three words—go to it!" So the plots at Waipio and Kailua

were set up. As time went on, the University added more members to my department and also more equipment.

The breakdown of the cane plant into its various parts, which is in common usage today, was worked out on this project. The beginning of numbering leaves from the spindle leaf downward was another innovation. In those days leaves were numbered from the one with the first visible dewlap—a method which frequently results in confusion.

Chemical analyses were adapted following the recommendations of Dr. Lyman Dean, then Head of the University's Soil Department—the same methods which are still being used today. From the beginning accuracy was insisted upon—the quick but inaccurate methods have no place in a control program. S. Moriguchi whose salary was paid by the HSPA was employed as the Analyst and Bruce Cooil, now Plant Physiologist at the University, then a graduate student, adapted the carbohydrate methods. Later T. Kubota came in and when he left, Gordon Shigeura, now Horticulturist at Keaau Orchard took his place. Later Minoru Isobe, now Assistant Agriculturist at HC&S Co. took Moriguchi's place.

The work was very absorbing, and actually during the first two years, it didn't occur to me that I had something of potential application to the plantations. But in 1940, I gave a lecture on the results of the work to date at a meeting of what was to become the Hawaiian Meteorological Society held in Dean Hall on the campus. At this meeting there were three people whom I was later to know as H. C. Penhallow, H. R. Shaw and A. C. Stearns. The point of the lecture was to show the influence of weather on plant growth and was given from the purely academic point of view.

By the middle of 1941, all the Waipio and Kailua crops had gone through one plant crop and were well into the ratoons. The amount of data, weather, chemical, growth, was indeed very substantial. The statistical work was already well on its way.

The works of Walter Thomas of Pennsylvania State College were very dominant then in the formative stages of my work. He took up the work of the two Frenchmen, Lagatu and Maume on foliar diagnosis. His work was a tremendous contribution to science and I was fully imbued with its importance. It did seem to me, however, a serious criticism of his work that he could not from his data predict the yields of his crops. He followed the Lagatu and Maume concepts that the recently matured leaves were the tissues to analyze. In fact, all the so-called foliar diagnostic methods adopted this as a general principle and apparently without question. Also, analyses were limited to the inorganic nutrient elements. It seemed to me, perhaps because of my interest in ecology, that if we didn't have a measure of the moisture level, the most important factor of the environment would be ignored; and secondly, probably because of my having been a student of E. J. Kraus at Wisconsin as well as at Chicago, that if we didn't have a measure of the plant's carbohydrate status we wouldn't have a measure of the plant's fitness to its environment. And so, these two new factors were added to the list of elements Thomas was reporting. Thus, crop-logging with these additions is considerably more than just foliar analysis. Also, I was determined to prove my index tissues. It seems rather an amusing commentary today that I am the only worker who ever has proved his tissues and yet now all that would be ignored. In fact, we have heard reference to foliar analysis which, of course, refers not to

crop-logging but to leaf analysis which never was proved and which I have shown to be rather undesirable. One other point—Thomas worked out an N-P-K unit and also a Ca-Mg-K unit involving a three dimensional portrayal emphasizing the idea of balance of nutrients on the one hand and their intensity on the other. It seemed to me, however, that, if we knew the amounts of each element and the desired level for each, meeting these levels would automatically provide the plant with the proper balances and intensity.

During the fall of 1941, I was attending a meeting of the Hawaiian Botanical Society. At this meeting Harold Wadsworth, now Dean of the College of Agriculture at the University, approached me with a man I knew to be Hamilton Agee. Mr. Agee, after whom this building is named was Agricultural Consultant for Castle & Cooke, Ltd. It developed that a meeting was held at Ewa, the point of which was to get at the causes for the serious decline of sugar yields at the Plantation. During these discussions Chad Penhallow, then an assistant in the research department at Ewa mentioned his hearing the lecture I had given the year before on sugar cane, and suggested that I be contacted. So the following week Mr. Agee and I took a trip to Ewa.

A short time later I gave a lecture on the whole program at a meeting of the Sugar Technologists held at the Moana Hotel. The reception of the idea was almost frightening because to see an idea clearly in one's own mind is one thing, but to implement it for plantation-scale operations is something else again. And certainly the idea was well received and some wanted to put it to work at once.

As some of you remember, a week later we had Pearl Harbor and for the next three or four months life here was fairly hectic. Although our field work continued on schedule, work in my University laboratory was limited because we couldn't work nights as had always been our custom. At any rate, along in February or March of 1942, Mr. Agee again got hold of me, and from here on crop-logging as applied to plantations began in earnest. The name crop-logging, suggested by Agee, was a good one although the Latin-American countries have trouble with it since there is no counterpart for log in their language. The French, Spanish and Portuguese refer to it as the "Agronomique Register de Clements" which is not nearly so good a handle as crop-log. At any rate after another visit at Ewa, the decision was made to set up a laboratory there. This was done by Billy Livingston with Jerry Wakatsuki as the first analyst. At Waiialua, Henry Chikasue was similarly chosen by A. C. Stearns, and at Kohala Kenneth Bond set up the laboratory with Kazuto Umamoto. Later, these labs were merged into the one at Pacific Chemical & Fertilizer Co., with S. Moriguchi in charge.

Those were busy days. I traveled about training people in all parts of the work—sampling, running analyses, interpreting results. Some of the men came to the University to learn the methods. Sometime later, A. D. Waterhouse was visiting at Kohala and heard about crop-logging from Kenneth Bond and soon Maui Agricultural Company was added to the list. At this stage, the late Dr. Arthur L. Dean and A. F. Anderson came into the picture with a request from the Maui plantation for service work by the chemistry department of the Experiment Station, HSPA, and this brought that department into the crop-logging picture. All the methods which had been in use by us at the University were now transcribed into the terminology of the RCM set-ups. In all cases we worked closely with this transition and certainly Dr. Hance and his department were a

big help in providing solutions, glassware, etc. As time went on, Mitsugi Doi has simplified some of the techniques and has trained many plantation analysts. The methylene blue method for the sugar analysis came from the Station. Also the leaf punch nitrogen technique was developed there, although using different leaves than are now used and these were also differently designated. Actually, some of the plantations continue to use the original official methods for both N and sugars.

In recent years, Dr. Kobe Shoji of the University Experiment Station has developed for sugar cane the use of the Beckman Spectrophotometer to give quick readings not only for potassium but also for calcium and magnesium. In this he received much help from Mr. Young of the Pineapple Research Institute.

But to return to 1942. Toward the end of that year, Mr. Agee died after suffering a heart attack. Hamilton Agee was one of the finest minds I ever knew. His counsels and warnings on the behavior of men have stood me in good stead many times. In fact, at the time of his death, he had written the first two pages of what he hoped would be a manuscript for a book to be entitled "The Cold Hand of Custom," a characterization of the difficulties encountered in introducing new ideas. He showed me these pages, but I never could locate them after his death.

During the next few years, we did a great deal of work at Ewa, particularly on nitrogen fertilization. Much of what we do today stems from these experiments which Billy Livingston and I walked through about once a week for at least four years. Multiple applications, second season applications, all were a part of this work.

At Kohala, Kenneth Bond and I ran many experiments particularly on potash and phosphate. These experiments rather definitely set the crop-log levels, which we now follow. At Waialua, following a year of very poor juices, the ripening program which we now use was developed, but that plantation didn't actually adopt it first. The then Young Turks at Maui Agriculture Co., Buckie Waterhouse, Frank Churchill, Asa Baldwin and Arthur Woolaway, actually put it to work first. And the results there were so outstanding that Waialua took it up, followed by practically all the other irrigated plantations.

By 1947 and 1948, life began to be fun. Not only was my work at the University going along full blast, but these first four plantations were really going places with yields, juices, and enthusiasm. In realms other than crop-logging, these four plantations carried the industry's ball on introducing 2, 4-D as a pre-emergence herbicide. In fact, on Friday, June 13, 1947, at Waialua an Andrews Flying Service plane put on the first 2, 4-D by plane to go into a cane field for pre-emergence control. I remember a session in Asa Baldwin's office at Paia during which I told him of the success of the pre-emergence experiments we were carrying on at Ewa and Waialua. Asa asked me if I'd be willing to recommend its application by air on a thousand acres of Maui Agriculture's cane, because while the fields were very clean then, the plantation was in danger of losing control because of excess open acres. After considerable mental squirming, I told him I would so recommend. So that's what they did and it did work very well indeed.

It was also at Maui Agricultural Company that the calculated second season nitrogen came into the picture. My ideas were pretty well formulated on the matter and I reviewed them at one of our sessions. So they took it up. In those days we thought sixty pounds were enough, but soon the calculations called for

more than a hundred pounds, but I didn't have the courage to go this far and for a while we pegged the second season nitrogen at a top of 100 pounds. Later, this was also adopted by Waialua with Walter Naquin as Agriculturist, and an experience at Waialua led us to pull out all the stops. The phrase "If the crop calls for it, put it on," became the common catch phrase. Now it isn't uncommon for fields to receive as much as 150 pounds during the second season with some going as high as 200 pounds. Totals for the two year crops range from 50-400 pounds. We have no reluctance to feed two year crops even up to 15 months of age particularly where we can use the ripening program.

The work on crop-logging I was doing at Waipio led to a study of soil moisture in relation to cane growth. The tensiometer was introduced at this point and this led to its adoption by HC&S Co. as standard procedure (this company had been merged with the Maui Agricultural Company). It became very evident to A. D. Waterhouse and to me that irrigation and interval control were much in need of work, and together we laid out a program of research which cleared up many problems and which is now being continued at that plantation.

Also, crop-logging is responsible for the recognition that adequate fertilization without adequate irrigation is just as frustrating to sugar cane as the other way around. In fact, I think that the crop-log with its portrayal of so many factors of the cane plant's physiology has enabled us to compound gains because of eliminating all deterring factors of growth while the cane is still in the field.

Now to continue with the development of the system. In early 1951, I was asked by H. K. Stender, Agricultural Consultant for the Hilo Coast Plantations, to give him a hand with the installation of crop-logging along the Hilo Coast and with his efforts to get the plantations on a higher plane of production. After a few more visits, I became Consulting Plant Physiologist for all the Brewer Plantations, in addition to my other assignments. I have enjoyed this new assignment no end not only because I enjoy working with the Brewer personnel, but because the problems on the unirrigated plantations are so varied I look upon this as an opportunity to broaden the scope of crop-logging. One thing is certain, the Hilo Coast with its very high rainfall has the best irrigation system in the world. Even Herbert Gomes now thinks the Olokele system a poor second! Being assured that the moisture requirements of sugar cane are satisfied, all we need do from the crop point of view is keep the fields clean and feed the plants properly throughout their cycles. The first logs showed the desperate need for more fertilization, better timing of fertilization, and definitely established the need for second season fertilization. At a meeting of the Brewer managers in Hilo, the idea of applying dry fertilizer by air was planted and the idea landed on very fertile soil indeed. Pepeekeo with Douglas Ednie and Renton Hutchison together with Murrayair pioneered the installation of the operation, putting in an air strip, getting the needed types of fertilizer, etc.

Although all the other unirrigated Brewer plantations also took up second season fertilization, Olaa uses the airplane even for its first season fertilization. With this operation now standard, fertilizing unirrigated fields can be done with the same precision which we had applied to irrigated lands. An even greater potential consequence of the airplane is the lengthening of the age of our crops, for this really is the next big step which we can make to reduce costs. Although we do not yet calculate second season applications, I hope to be able to develop this.

In addition to the obvious problems associated with mechanization which our engineers are solving, a big remaining problem for the unirrigated plantation is a ripening procedure which would parallel the ripening on the irrigated plantation. In my mind, there is no question about either the physiological feasibility of building up the sugar content of the cane or the economic desirability of this process. On the irrigated plantations the problem has largely been solved so long as we have control of water. But on the unirrigated plantations during wet cycles, and on the unirrigated plantations, the problem remains. Essentially what we accomplish when we ripen fields by withholding water is that we restrict growth while we allow photosynthesis to continue. Where normally a substantial part of the sugar produced goes into the production of cellulose and new protoplasm, by reducing this diversion we can increase the rate of sugar deposition in the stalk. In my mind there is no question about this. I have published results of analyses which definitely establish the addition of sugar to internodes long after the attached leaf has fallen. Now, since in this era of anything being possible if we once know what we want, I have on several occasions spoken to representatives of the various chemical companies and pointed to the need for a compound which would reduce or stop growth but not at the expense of reducing photosynthesis or increasing respiration. If respiration is increased, as is accomplished by many of the common hormones, there is a loss of sugar. Also, of course, putting on oil or herbicide killers is not ripening. But I think that one day we shall have what is needed.

Another development which is now unfolding has to do with the need for calcium and magnesium. Because of Dr. Shoji's work with the spectrophotometer, the analyses for these two elements are made on an extract from the revised phosphorus determination. With the instrument, calcium and magnesium analyses instead of being a very involved chemical procedure are now only push button affairs. All the Brewer plantations using the Crop Log Laboratory at Onomea are getting these analyses on the same samples which are used for phosphorus. In other words, these are on three consecutive samples taken between 6-15 months of age during the May through October period. Tentative normal levels for Ca are set at 0.200 and for Mg 0.175. Both of these values are on the per cent sugar free dry matter of the young sheaths.

Minor elements are being covered in field testing on all the Brewer and Castle and Cooke plantations, besides HC&S Co. and Pioneer Mill Company. The involved analyses of the samples for all the minor elements and silicon are being run by Dr. Kobe Shoji of the University Experiment Station and are nearly completed. The territory-wide survey should soon appear as a Technical Bulletin from the University's Experiment Station.

Thus, all the essential elements will ultimately be included in crop-logging. With the work on irrigation which has already been done and which is continuing, we will have full appreciation of the moisture side of plant life. The ripening program takes care of the last phase of the crop life. Thus, essentially all parts of the cane's physiology are being included to make the crop-log a complete picture of the crop.

Now I should like to conclude this paper with a description of a portion of crop-logging which has not gone into general use as yet.

If a system which is being followed in crop production is accurately integrated

with the factors of production, then it should be possible to develop formulae which can be applied not only as a prediction of anticipated yields, but as a test of the system used. From statistical analyses reported in Technical Bulletin No. 18 of the University Experiment Station, a growth equation for sugar cane which is the simplest to apply is as follows:

$E = 0.0820X_1 + 9.3206X_2 - 0.0979X_3 + 2.8025X_4 + 3.2272X_5 - 1130.9004$   
 where E is the estimated growth unit per period,  $X_1$  is the average sunlight per day for the period expressed as gram calories per sq. cm. per day,  $X_2$  is the sheath moisture,  $X_3$  the age of the crop in days,  $X_4$  is the average maximum temperature ( $^{\circ}\text{F}$ ) per day for the period, and  $X_5$  the average minimum temperature ( $^{\circ}\text{F}$ ) per day per period. The period referred to is the 35-day period which normally occurs between samplings.

Now at Ewa the sampling is very standard and is thoroughly and carefully done. When the crop-log data from Ewa, field by field, come to my desk, they are entered into the record, along with the average light and temperature readings. The calculation is made and the growth unit for the period is entered. In order for the estimate to be useful and also escape the charge of "fixing," it needs to be made late in the year prior to the crop year. Thus, for Ewa's 1954 crop, I ran all the calculations in October of 1953 and sent the estimate to Robert Cushnie, Field Superintendent, prior to the release of the plantation's official estimate. Because the expected age of the crop is one of the factors in the formula, I asked Cushnie to give me the expected age at harvest. Since this estimate has to be made before the crop is ready, it seems best to use the crop-log values for the first twelve months of each field crop. The growth unit values for the first year will always average higher than the second and, therefore, all the average growth units for the field at 12 months are divided by a constant factor for all fields. For the 1954 crop, the factor was 1.377. This average growth unit is then multiplied by the expected age in months and this value then represents the total growth units for the crop. This total is next multiplied by a conversion factor to convert to tons cane per acre. A curve was developed which has the equation  $Y = .29684 - .04370559X + .00311722X^2 - .00010244X^3 + .00000127X^4$ , where Y is the conversion factor and X is  $\frac{1}{5}$  of the average growth unit for the field. This curve was developed when it was discovered that the conversion factor was related to the size of the growth unit. Hence, knowing the growth unit for the particular field crop, one needs only to go to the curve and for the appropriate growth unit read off the conversion factor with which to multiply the total growth units and this gives the tentative estimate. This tentative estimate assumes a completely uniform field which of course practically never exists, but if a field has weaker areas than the sampling stations or stronger areas than crop after crop, the deviation from normal should be more or less of a constant. Knowing the departures from normal for each field is simply a matter of record. These departures are now applied to the tentative estimate and the growth unit estimate emerges. In Table 1, I report all the Ewa crop of 1954 except three small areas for which there were no log data. Included in the table are the official estimate made by the plantation officials and the growth unit estimate made by myself—both being made in October of 1953—and the actual yields as obtained in 1954. Opposite some of the growth unit estimates is an asterisk which indicates that this estimate was as close as or closer than the official estimate. In 30 out of 47

TABLE 1. EWA PLANTATION CO. 1954 CROP ESTIMATES AND ACTUAL YIELD

Field	Official Estimate TCA	Actual Yield TCA	Growth Unit Estimate TCA
3	95	98	103
11.2	110	113	119
20.1	95	102	107*
23.1	110	114	111*
24	120	124	121*
41	115	120	120*
49.1	110	119	110*
57.1	110	121	115*
57.2	105	119	99
68	105	116	113*
78.1	100	102	122
79.5	100	91	93*
1	100	108	105*
5	90	97	101*
50	115	128	118*
51	110	116	115*
52	105	112	110*
63.3	100	108	110*
10.1	100	103	100*
12	95	88	103
13	95	103	107*
14.2	120	120	133
17	115	132	126*
32	120	129	122*
34	100	122	120*
49.2	115	139	125*
55	105	111	113*
62	105	97	92
64	90	89	106
69	115	130	128*
70.1	115	121	131
77	100	100	106
79.2	80	77	97
79.3	80	99	99*
80	95	98	88
81	90	93	100
6	100	99	108
20.2	115	128	133*
21	100	120	112*
29	100	118	125*
33	110	123	122*
48	110	124	122*
70.3	95	101	101*
73	115	125	119*
75	110	113	109
10.2	85	91	109
43	90	91	94
Ave.	103.4	110.5	111.5

this was the case. The correlations between estimated and actual yields are the high values of  $+ .859$  for the relation between the official and actual and  $+ .788$  for the relation between the growth unit estimate and actual. Thus, although the correlation is better for the official, ( $+ .071$ ) the actual unweighted arithmetic growth unit estimate of 111.5 is much closer to the actual of 110.5 than is that of the official estimate 103.40.

The 1953 Crop at Ewa was similarly estimated. In 29 out of 49 cases the G.U. estimate was as close as, or closer than, the official estimate. The official estimate averaged 105.33 TCA, the Growth Unit estimate 107.47 TCA and the actual crop figure was 109.83 TCA. The correlation between the official estimate and the

actual yield was .901 and that between the Growth Unit estimate and the actual yield was .862.

When both crops are combined, the official estimate was 104.4 TCA, the Growth Unit estimate 109.4 TCA and actual yield was 110.1 TCA. The correlation between the official estimate and the actual yield was .867 and that between the Growth Unit Estimate and the actual yield was .810.

The Growth Unit estimate is not offered here as an improvement on the official estimate, but rather as a practical demonstration of what amounts to a mathematical test of the reliability of the crop-log and its underlying philosophy.

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## EXPERIENCES WITH CROP CONTROL IN JAMAICA

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To quote Dr. L. D. Baver and Mr. W. W. G. Moir, "Jamaica is an interesting island in that it appears to be a land of samples." This is particularly true of factors influencing the nutrition of sugar cane. A complex geology has given rise to soils with a great range of ability to supply potash and phosphate, although the areas of phosphate deficiency are not nearly so great as those of potash deficiency. Acid soils do occur, but pH's are generally high and plant nutrition is complicated by excessive concentrations of free calcium carbonate in many soils. Quite aside from these soil factors, productivity is greatly influenced by the water supply which ranges from a well-distributed natural rainfall of 90 or more inches per annum where irrigation is adequate, to a poorly-distributed rainfall of 40 inches in the non-irrigated areas where water is a severely limiting factor. Other considerations are that large tracts of uniform soil are rare and that the average field size is about 10 acres. And when discussing the quantitative aspects of nutrition, it should be remembered that we deal with cane which averages 12 months of age at harvest.

The detailed field-by-field control of the nutrition of sugar cane is therefore not easy. The practice evolved has been to maintain a network of reference factorial experiments dispersed over the cane area in such a way that the complete range of growing conditions is covered and the results of the experiments are then tied to the peculiar conditions prevailing on individual fields. The network of field experiments is a perpetual one. Each experiment is designed in the light of accumulated knowledge and is continued for a full crop cycle. Whenever possible, the linear interactions between the three principal plant foods are measured, using at least three levels of all elements calculated to be in limiting supply. It has been usual to insist on two levels of application even when the supply of one element is estimated to be adequate. The designs most popular, therefore, are the  $3 \times 3 \times 3$  (arranged in three blocks of nine treatments),  $4 \times 3 \times 3$ , and  $4 \times 3 \times 2$  factorials, and sometimes one-third replicates of  $3 \times 3 \times 3 \times 3 \times 3$  designs. In all, about 100 fertilizer experiments are in operation at any one time and conclusions are based upon recoverable sucrose/acre/12 months.

Over the years, a considerable body of data has been accumulated which reflects the changes in nutrition of cane resulting from certain policies of fertilization.

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The three or more levels of application allow derivation of useful quantitative relationships between treatment level and optimum economic response. The regressions are capable of a working definition, using curves of the Mitscherlich type in which

$$k = \frac{1}{b} \log_{10} \frac{Y_2 - Y_1}{Y_1 - Y_0} \quad (1)$$

when the levels of treatment are equally spaced, say at  $a$ ,  $a + b$ ,  $a + 2b$ , etc. Working values of  $k$  have been found to be:

$$k_N = 0.010 \quad k_P = 0.010 \quad k_K = 0.012 \quad (2)$$

when the treatments are expressed in lbs/acre of  $N$ ,  $P_2O_5$  and  $K_2O$ . The logarithmic relationship is accepted as a useful hypothesis only, and not as a natural law. Undoubtedly many other regressions could be fitted, a polynomial for example being equally good mathematically. The values of the constant  $k$  are influenced by the magnitude of the response to unit dressings, the value of  $k$  varying as an inverse function of the maximum expected response. The figures quoted in (2) represent working averages.

Before leaving the subject of experimentation, reference should be made to the problem of whether it is wiser to establish control in advisory work by reference to a limited number of formal experiments of relatively high individual accuracy, or to rely on a broader coverage of sites by splitting up formal experiments so that their component blocks are no longer contiguous, but are dispersed into different fields. The problem is currently being faced in many countries. A modification of the principle has been used by Bray for many years. At present, we are engaged upon a program of work designed to test whether or not the fragmentation of formal experiments does in fact offer a better advisory tool under our highly varied conditions of sugar cane cultivation than does the older system. The new method will enable us to deal with more than 300 sites per annum as against our present figure of about 100.

## RESULTS OF FIELD EXPERIMENTATION—A SUMMARY

### Nitrogen

As might be expected, optimum  $N$  dressings are related to available water and whether or not the crop is plant or ratoon. Table 1 summarizes the conclusions reached from our field experiments. The figures apply to cane which is harvested with the trash unburned.

TABLE 1. S/A REQUIREMENTS OF SUGAR CANE IN JAMAICA  
Cwts S/A per acre

Area	Plant	Ratoon
Irrigated.....	2-4	3-6
Heavy rainfall (90").....	2-3	3-5
Medium rainfall (50-60").....	2-3	2-4
Low rainfall—non irrigated (<50").....	2	2

Anomalous fields occur on which plant cane requires no nitrogen dressings. These generally consist of land formerly in pasture, or of old banana fields, as well as old cane fields on lateritic soils in low rainfall areas. When water is adequate 50 and more tons of cane per acre can be obtained in 12 months at the rates of nitrogen application indicated.

## Phosphate

Phosphate response is related to soil type, being greatest on acid secondary soils derived from alluvial clays, red weathering soils derived from shales and tuffs, and certain highly calcareous, rendzina-type soils. The optimum economic dressings rarely exceed four cwts/acre of 18 per cent superphosphate per annum and are generally between two and four cwts. The average dressing of phosphate actually applied by estates works out to 37 pounds per acre of water-soluble  $P_2O_5$ . Our observations lead us to suspect strongly that the efficiency with which applied phosphate is recovered by the cane depends largely upon soil tilth and the development of a vigorous root system.

## Potash

Experiments confirm the belief that sugar cane responses to applied potash are closely related to soil type and are of considerable importance to our industry. Table 2 shows this.

TABLE 2. THE RESPONSE OF SUGAR CANE TO APPLIED POTASH

Soil	% Mean increase to 1½-2 cwts/acre Muriate of Potash (60% $K_2O$ )
Recent river alluvium (irrigated).....	5.6
Recent river alluvium (heavy rainfall).....	5.4
Marine clay soils (irrigated).....	3.5
Secondary soils from alluvial clays:	
(heavy rainfall).....	36.6
(medium rainfall).....	55.3
(low rainfall (lateritic) ).....	77.6
Rendzina soils (low rainfall).....	5.5
Soils from tuffs, shales and conglomerates:	
(Medium rainfall).....	7.0

Today, about 40 per cent of our cane area receives potash at an average rate equivalent to 96 pounds of  $K_2O$  per acre/annum.

## INTERPRETATION OF THE SPECIFIC FERTILIZER REQUIREMENTS OF INDIVIDUAL FIELDS

The universal and well-known problem of obtaining information on the qualitative food requirements of a standing crop, and the estimated quantitative reaction of the crop to fertilizer treatments, all predicted with a calculated accuracy, have confronted us as they have confronted you. Ideally, the methods developed must be able to give a 'running commentary' of the crop's state of nutrition, as well as to predict responses to applied fertilizers quantitatively. The limitations of the soil analytical approach are well understood, especially with nitrogen, and even with the other major plant foods when the range of soils covered is extreme and when excesses of free calcium carbonate have to be contended with. Although we are working on the soil analytical approach and believe that it has a place as one of the advisory tools in formulating a fertilizer policy, we have devoted most of our attention so far to an attempt to elucidate the problem of the field-by-field nutritional control of cane by the reaction of the plant itself. In this, we were encouraged in our earlier days by the way in which the chemical composition of our arbitrary index tissue (the third fully-opened leaf) varied

with soil type and generally reflected the information we already had about crop responses on the soils concerned. Table 3, which summarizes some of these data, is based upon the analyses of cane leaf material from numerous fields considered typical of each soil type.

TABLE 3. THE RELATION BETWEEN SOIL TYPE AND CANE (WHOLE) LEAF COMPOSITION

Soils	N	P <sub>2</sub> O <sub>5</sub>	K <sub>2</sub> O	Remarks
Rendzina.....	1.08	0.29	1.69	Phosphate deficient—slight potash deficiency
Inland basin alluvia....	1.30	0.43	1.07	Potash deficient
Eroded basin alluvia....	1.12	0.28	1.44	Phosphate & potash deficient
Soils from shales & tuffs.	1.22	0.27	1.40	Phosphate & potash deficient
Coarse recent alluvia....	1.31	0.39	1.22	Potash deficient
Highly fertile alluvia....	1.36	0.47	2.10	

Later work showed that the leaf lamina was much more sensitive to variations in phosphate and total nitrogen, without being appreciably less sensitive to potash variations. Consequently, a systematic investigation was undertaken to determine whether the seasonal composition of sugar cane leaf material was capable of giving accurate quantitative indications of the response of the crop to applied fertilizers. The network of field experiments in operation was used as raw material; each plot in each experiment was leaf-sampled at frequent intervals throughout the year and the composition of the dry matter of the lamina of the third fully-opened leaf determined. The statistical analyses of these data have led to the conclusions which will now be presented. It is well to state here that the results obtained from the single sampling of single experiments are capable of revealing highly significant nutritional interactions, and of giving interesting regressions between interval composition and treatment as well as yield, but these relationships vary greatly between different sampling times and between different sites. To date, therefore, we have accepted the principle that the bulk of the data must be capable of analysis as a whole to give generalized conclusions applicable over the range of cane-growing conditions met in our sugar industry. The extent to which this could be possible would largely determine the usefulness (or otherwise) of cane leaf composition as an advisory tool on an industry basis. We have no doubt that had our conditions of sugar cane production been much more uniform, the relationships which we will discuss would have been more accurate. In spite of this, we have been able to obtain working relationships of a quantitative nature which have enabled us to guide with fair accuracy the policy of sugar cane fertilization in Jamaica under widely varied conditions.

### Nitrogen

Like much other work on sugar cane, our data show that the level of nitrogen in cane leaves not only falls with the age of the plant, but that it is very sensitive to the supply of available moisture. Droughts bring about a severe drop in leaf nitrogen figures, as do also conditions of poor tilth and inadequate soil aeration. One has therefore to be particularly careful when attempting to interpret leaf nitrogen figures, since conclusions are only valid when the plant has suffered no water shortage for some period prior to sampling—a period probably of the order of four weeks.

The regression between the relative production† of sugar per acre (Y) as a result of applying the optimum economic dressing of nitrogen and the N per cent leaf dry matter (X) in the absence of nitrogen applications, is highly significant, and can be well met by linear equations since the curvature of the best-fitting logarithmic relation is small. Averaged over plant canes and ratoons, the following relationships hold:

<u>Sampled at 4 months</u>	<u>Sampled at 5 months</u>
$Y = 181 - 33X^*$	$Y = 216 - 55X^{**}$
or $Y = \frac{165^*}{X^{0.384}}$	or $Y = \frac{167^{***}}{X^{0.603}}$

\* Significant at 20:1 point. \*\* Significant at 100:1 point. \*\*\* Significant at 1000:1 point.

The linear equations and their 5 per cent fiducial limits are presented as shaded bands in Figure 1 from which it may be argued that, on the whole, cane giving leaf nitrogen per cent dry matter figures at four months of less than 2.4 (from linear regression) to 2.6 (from logarithmic regression) will respond to applications of nitrogen. At five months, both regressions give a critical value of 2.3 per cent. Unfortunately, the fiducial limits of the relationships are so wide that although the mean regression can be used in predicting yield responses to optimum nitrogen dressings, the prediction will not be very accurate. The critical value at five months derived from the regression for ratoons only,  $Y = 336 - 129X^*$ , is 1.83.

At the level of accuracy attained by our experiments, increases in yield of 6 per cent, when averaged over 16 or more experiments, can be considered significant. Table 4 shows the percentage of all experiments which gave yield increases of more than 6 per cent or less than 6 per cent, classified according to the level of increase in leaf nitrogen brought about as a result of applying the nitrogen treatment.

The figures suggest that increases of 6 per cent or more in leaf nitrogen are associated with significant increases in sugar per acre and, indeed, a working

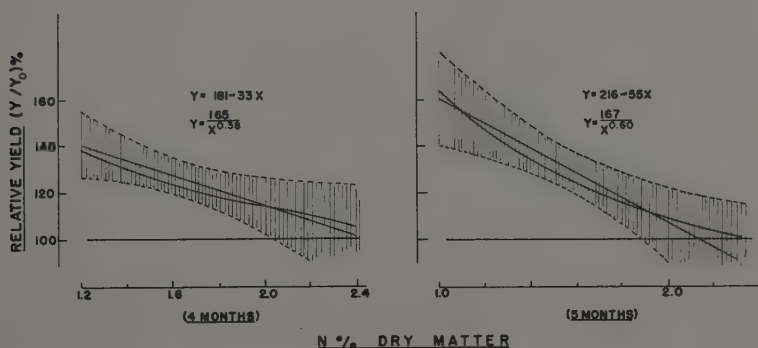


Figure 1

† Relative production = production obtained from treatment expressed as per cent of production obtained from control.

TABLE 4. PER CENT OF ALL EXPERIMENTS CLASSIFIED ACCORDING TO RELATIVE INCREASE IN LEAF NITROGEN AND CORRESPONDING RELATIVE INCREASE IN YIELD OF SUGAR/ACRE

% relative increase in N% dry matter as a result of treatment	Leaf sampled at 5 months		Average Yield inc. %
	Yield Response 0-6%	+6%	
0-5 .....	16.4	12.4	5.7
6-10 .....	6.2	15.9	13.3
11-15 .....	2.1	10.4	17.2
16-20 .....	2.1	10.4	40.0
21-30 .....	1.4	11.7	33.2
31-50 .....	0	9.3	70.6
Over 51 .....	0	2.1	71.0

quantitative prediction of relative responses to nitrogen dressings was found by relating relative yield to the corresponding relative leaf nitrogen levels. Thus the treatment which produced an increase of X per cent in N per cent dry matter resulted in Y per cent increase in yield of sugar per acre. The relationships are linear, are very highly significant and, averaged over plants and ratoons, are of the form:

- (a) at 4 months  $Y = 1.18X - 13.1$  (significant at greater than  $10^9:1$ )  
and (b) at 5 months  $Y = 1.33X - 27.0$  (significant at greater than  $10^9:1$ )

These equations with their 5 per cent fiducial limits are expressed as bands in Figure 2 from which it is evident that they might form a useful basis of prediction, with reasonable accuracy.

An earlier analysis of some data for five months' sampling gave a value of 1.2 for the slope of the regression, and the relationships averaged over all our data for ratoons and plants individually at five months' sampling, gave slopes of 1.29 and 1.20, respectively (each significant at infinity). It seems reasonable, therefore, to accept that any nitrogen treatment which increases leaf nitrogen at three to five months by X per cent will result in an increased yield of sugar per acre of from 1.2X to 1.3X per cent.

On irrigated estates, nitrogen fertilization is controlled by augmenting ordinary leaf nitrogen data by placing, on as many fields as possible, small contiguous plots each treated with one of three or four increasing levels of nitrogen. The dressings of nitrogen made to fields in the normal course and based upon field experiments and accumulated knowledge, are checked and modified in the light of the relative leaf nitrogen values found in the small plots at three to four months. On the other sugar areas, reliance is placed in a qualitative manner upon leaf nitrogen values at five months and upon the results of numerous factorial experiments. These latter are now being fragmented to obtain better cover and classification of variance.

The method of controlling nitrogen still leaves much to be desired but, on the whole, the average applications made to cane are now fast approaching the mean optimum figures derived from the large number of experiments in operation.

### Phosphate

The uptake of phosphate as reflected in  $P_2O_5$  per cent dry matter of the lamina of the third fully-opened leaf is influenced not only by the application of phosphate but also by the application of nitrogen and potash when these influence yield

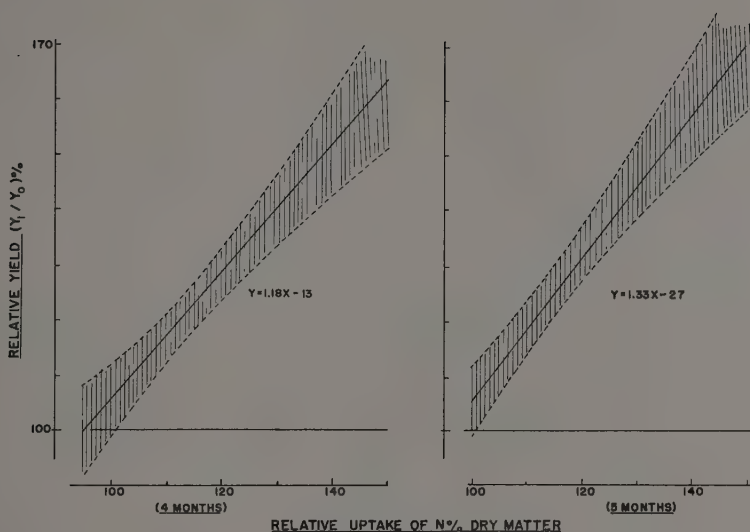


Figure 2

significantly. The effects of this interaction are not discussed here, but rather, the relationships between phosphate and sugar per acre averaged over all effects.

The response of the phosphate status of the lamina of the third fully-opened leaf to a standard dressing of superphosphate (3 cwts. per acre per annum of superphosphate 18 per cent  $P_2O_5$ ) is highly correlated with what would have been the level of phosphate in the leaf had no superphosphate been applied. The relationship is curvilinear. The two hyperbolic regressions which fit the data for samplings at four and five months respectively are:

At 4 months

$$Y = \frac{206}{X^{0.39}} \text{ (significant at infinity/one)}$$

At 5 months

$$Y = \frac{168}{X^{0.28}} \text{ (significant at infinity/one)}$$

From Figure 3 in which these regressions are plotted along with their 5 per cent fiducial limits, it is evident that, on the average, applied superphosphate will have little or no effect upon the level of phosphate in the lamina of the third fully-opened leaf sampled at four to five months if this already stands at 0.57 per cent  $P_2O_5$  or more. In other words, on the whole, the critical value of phosphate in the index tissue defined at four to five months is probably around 0.63 per cent  $P_2O_5$ , and not less than 0.57 per cent.

If the relationship between phosphate level in the index tissue (X) and relative sugar production (Y) to a standard dressing of superphosphate (3 cwts. per acre per annum 18 per cent  $P_2O_5$ ) is examined, it can be shown that significant regressions are possible, but that the regression at four months' sampling is much more accurate. The curvatures of the regressions are not significant. The linear equations which are as follows:

At 4 months

$$Y = 141 - 69.5X \text{ (significant at greater than 10,000:1)}$$

At 5 months

$$Y = 126 - 44.6X \text{ (significant at greater than 100:1)}$$

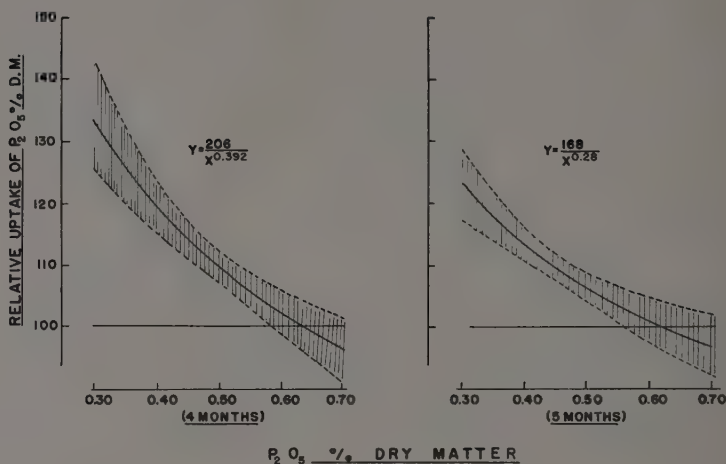


Figure 3

are plotted along with their 5 per cent fiducial limits in Figure 4. Sampling at four months is more sensitive than sampling at five months. Accepting the four months' relationship, we have concluded that responses to applied phosphates are likely to be obtained when the P<sub>2</sub>O<sub>5</sub> per cent index tissue is less than 0.58 per cent, but for advisory purposes, we have accepted a limit of 0.50 which coincides approximately with the lower fiducial limit of the relationship and is therefore very safe. Apart from this, according to the mean relationship, at P<sub>2</sub>O<sub>5</sub> figures of 0.50 or less, the average expected response to 3 cwts per acre of superphosphate (18 per cent P<sub>2</sub>O<sub>5</sub>) would be 5 per cent or more, which would show an economic return at current prices and at an average yield of 30 tons cane per acre per annum (9.0 tons cane per ton sugar).

The data also show that very highly significant linear relationships\* exist between the relative uptake of phosphate in the index leaf tissue (X) and the

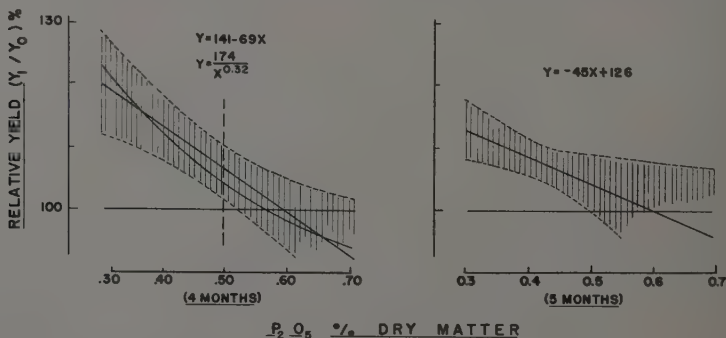


Figure 4

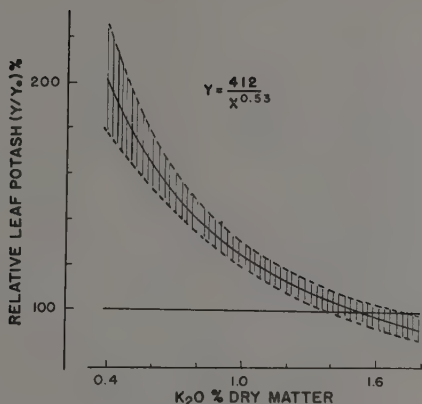
\* At 4 months

$Y = 0.41X + 59$  (significant at infinity/one)

At 5 months

$Y = 0.32X + 70$  (significant at infinity/one)

Figure 5



relative sugar production (Y), each consequent upon the application of the same amount of superphosphate to the soil; i.e., as with nitrogen, relative increases in leaf phosphate can be used to predict relative increases in sugar per acre. No advisory use has been made of the regression since it would be impracticable to correct an inadequate phosphate uptake by phosphatic dressings when the cane is four months old and older.

Much room remains in which to narrow the fiducial limits of the relation between  $P_2O_5$  per 'cent index tissue and the expected sugar-per-acre response to a standard dressing of superphosphate. In the meantime, a workable advisory procedure of known, but only fair accuracy, is available.

### Potash

The potash relationships refer to cane which is around five months old and sampled between July and October. The level of potash in the leaf lamina tissue has been shown to be linearly related to the available potash in the soil, the latter being determined from the response curves of field experiments. The data also show that the relative uptake of potash in the leaf (Y) as a result of applying a standard dressing of muriate of potash (2 cwts per acre) is hyperbolically related to the potash content of the leaf dry matter (X) in the absence of potash applications. The equation is:

$$Y = \frac{412}{X^{0.529}} \text{ (significant at infinity/1)}$$

which is similar to the behavior of phosphate uptake. The relation is plotted in Figure 5 which suggests that, on the average, applications of potash of the order of 2 cwts per acre muriate of potash (60 per cent  $K_2O$ ) are not sufficient to bring about luxury uptake of potash in the leaf lamina if the concentration of potash in this tissue already stands at 1.5 per cent  $K_2O$  or more.

The regression between the relative production of sugar (Y) as a result of applying muriate of potash, and the per cent  $K_2O$  in the lamina of the third fully-opened leaf (X) is highly significant and of the form—

$$Y_{(k_1)} = \frac{115}{X^{0.46}} \text{ (significant at infinity/1) when 1 cwt/acre KCl is used.}$$

$$\text{and } Y_{(k_2)} = \frac{118}{X^{0.49}} \text{ (significant at infinity/1) when 2 cwts/acre KCl are used.}$$

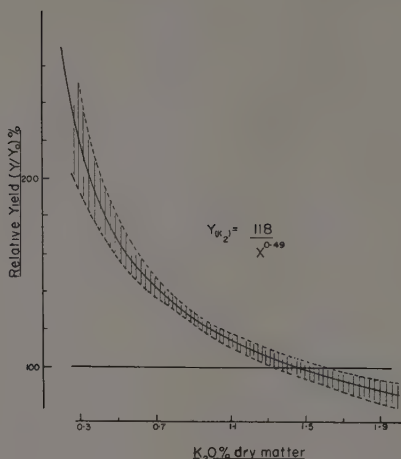


Figure 6

The second regression and its fiducial limits are given in Figure 6. Both equations give an average limiting value of 1.4 K<sub>2</sub>O. For advisory purposes, a critical value of 1.3 per cent K<sub>2</sub>O is accepted since this coincides with the lower fiducial limit of the regression. Furthermore, below this value, increases of the order of 5 per cent and more would be expected from an application of 2 cwts per acre of muriate of potash; i.e., increases greater than the break even value for 2 cwts muriate of potash at current prices. The same conclusion is reached from the curve based upon responses to 1 cwt per acre muriate of potash.

As with phosphate and nitrogen, the relative yield of sugar per acre (Y) as a result of a standard dressing of potash is linearly related to the relative level of K<sub>2</sub>O in the leaf tissue (X) consequent upon applying the potash dressing, such that—

$$Y = 0.96X + 2.8 \text{ (significant at greater than 1000:1)}$$

The regression has not been used for advisory purposes.

## Conclusions

The plant composition approach to the field by field control of the nutrition of sugar cane is possible. So far, the data relating to potash are by far the most accurate, and those relating to nitrogen the most unsatisfactory. We have been able to adjust the phosphate and potash status of sugar cane over widely-differing soils in a manner which has subsequently been confirmed by field experiments, but we still rely, in the main, on the accumulated results of field experiments in regard to nitrogen.

## SUMMARY

1. The control of the nutrition of sugar cane in Jamaica has been discussed with reference to field experimentation and the derivation of a complementary advisory procedure based upon the composition of an index tissue.

2. Fertilization is based upon results from a network of factorial experiments in continuous operation.

3. Critical or limiting values for leaf nitrogen are of significance but must be interpreted with caution. Leaf nitrogen cannot as yet be used to predict quantitative responses to nitrogen.

4. A method of nitrogen control based upon the response of the leaf nitrogen to nitrogen applied during the first four months of growth is of value on irrigated estates in assessing nitrogen applications already made.

5. The behaviour of leaf phosphate to standard dressings of superphosphate, as influenced by the level of phosphate in the leaf in the absence of phosphatic dressings, has been defined.

6. It has been possible to establish a limiting or critical value for leaf  $P_2O_5$  and to derive a relationship of fair accuracy between phosphate in leaf lamina material and the quantitative response to a standard dressing of superphosphate as measured by sugar per acre.

7. The relation between the increased potash status of lamina dry matter as a result of applying standard dressings of muriate of potash has been shown to be a function of the level of potash in the leaf in the absence of potash manuring.

8. The relative increase in sugar per acre from a standard dressing of muriate of potash is quantitatively related to the potash content of the leaf lamina with sufficient accuracy not only to justify a limiting or critical value of leaf potash, but also to predict economic potash dressings.

#### ACKNOWLEDGMENTS

We are indebted to the Director of the Experiment Station, HSPA, for the invitation to present this paper and for being able to send a representative to the seminar. For both these opportunities, it is a pleasure to offer our thanks.

## DISCUSSION

**H. Gomes:** What are the yields on your crop at Jamaica?

**T. Chinloy:** Under adequate water relationship, we get on the order of 60 tons per acre. Sugar—about five tons of sugar.

**Keith Tester:** In this example you have here, Mr. Chinloy, when did you put on the final dressing of nitrogen?

**T. Chinloy:** Between four and five months old.

**Walter Naquin:** How was that applied?

**T. Chinloy:** By hand.

**W. W. G. Moir:** Dr. Bayer, I think it should be pointed out that this four or five months' period in which they get this index is in the ideal time of the year, in April, May or June, when the sample is taken. If we were to try to get our data on that same basis, we might get something very similar. The relationship of time of year is very definitely in the picture.

**L. D. Bayer:** Of course, I was down there in the wet season, and the thing that impressed me with the young cane is how it takes off a little faster than ours does here. At four months old, I believe your cane was a little bit bigger, maybe, than our four month-old cane.

**T. Chinloy:** I'm afraid I don't know much about that, but I agree with Mr. Moir—we find the time of taking the sample very important.

**H. F. Clements:** When do you do your harvesting?

**T. Chinloy:** We start on some estates in September and we go on some estates until July.

**John Warner:** How many of these large factorials, that is  $3 \times 3 \times 3$  and  $4 \times 3 \times 2$ , do you put in each year?

**T. Chinloy:** We operate a total of about 100 of these factorials per year. That means we put in about 33 per year, because they are operated through one plant and two ratoon cycles.

**John Warner:** Are those 33 experiments, or 33 replications?

**T. Chinloy:** 33 new experiments.

**John Warner:** How many replicates of each?

**T. Chinloy:** A total of 37 plots. It depends upon the type of experiment we use. For instance, in  $3 \times 3 \times 3$  we expect to use only single replicates in three blocks of nine.

**L. D. Bayer:** I would like to comment on one thing that you mentioned about this question of breaking up your experiment, that we are using that principle here with very good effect by putting the replicates on different plantations. Mr. Chinloy, I want to thank you very much for coming out to be with us.

## SUMMARY

L. D. BAVER

According to the program, I am supposed to make a summary of suggestions from the nutrition seminar. That meant I was supposed to write my paper while the folks were in the process of giving theirs. Right now, my paper is being written as I talk into this machine.

I am very much interested in these discussions we have had today. You shouldn't be disturbed at all that there have been differences in opinion, because differences of opinion are always a sign of progress.

As I have listened to the discussions the last two days, I believe that if I could come up with any particular suggestion that would be nearly 100 per cent true, it would be that the discussions have proved that the problems of crop control have not been completely solved. The final answer is not in. We should again think in terms of the fact that the techniques that everybody has discussed in such a very fine manner are only tools that we use in farming operations. They themselves would not be too useable without the use of good judgment.

The question comes up as to the basis, usually, of varying differences in opinion. That might vary somewhat, too. We may be in a situation like the farmer out in Kansas who was sitting on a rail fence one day when a New Yorker came by in one of those convertible automobiles. He saw the farmer sitting there on the fence; so he stopped, thinking he would have a little fun with him. In the process of the discussion, he said to the farmer, "This must be quite a lonely life for you out here. Just look at me. I have this big car. I can drive all over the country." "Well," the farmer said, "You know, that's just a difference in the point of view. I sit here on a rail fence and watch the cars go by. You sit in the car and watch the rail fences go by."

Generally speaking, there are several causes of differences in opinion. I will enumerate a few. One cause of differences of opinion between technical men may be due to the fact that there are inadequate data to give a complete picture of the problem. I am not saying that this is the case in the present discussions. I think that we have seen, for example, that there are opportunities for clarification of many of the issues with more data, and I will have some to present in just a minute. Now, if we have adequate data on a subject, we might find differences in opinion arising as a result of differences in the interpretation of the meaning of the data. The individuals interpreting such data are doing so on the basis of their experiences. We have visualized in our seminar interpretations of interesting data. I think all of the data which have been presented here today and yesterday should not be challenged from the standpoint of scientific accuracy. Consequently, if there are differences in the interpretation of the data given, then that reflects the experiences of the individuals involved.

Another reason for differences of opinion might be that there is an incomplete understanding of points of view. In other words, even with the same data, which seem to be interpreted differently, we would not be too far apart if we really understood the other person's point of view. I have a feeling that this has been true of a lot of the discussions which seem to point to quite a difference of opinion

on some of the data presented. Now, since we look at these differences of opinion objectively, let us wait and see what we are going to end up with after all of the data are in. Let us chop wood and let the chips fall where they will. Whoever is hit on the head with the chips should be a big enough individual to change his opinion. Otherwise, it is going to be mighty hopeless for the future program of crop control in Hawaii.

We have seen in this particular seminar some of the values that come out of objective research. We have seen Dr. Clements, for example, present two rather striking illustrations of the scientific approach for improving the accuracy of several determinations which have been questioned as far as some of the strategy that he has been using with respect to crop logging is concerned. I refer to the improvement that he mentioned with respect to leaf sheath phosphorus and leaf nitrogen. I think we all should accept those particular data as one step forward in the improvement of the information and know-how that we use in crop logging and crop control work in the production of the sugar cane crop. As I sat here, I came to the conclusion that after all is said and done, one of the reasons for the differences in opinion happens to be slightly different approaches to the objective. Plant analyses have been used to achieve the objective. In the one case, the general point of view is to sample the growing parts of the plant which are considered the key parts. The total composition of these key parts with respect to the various nutrients that come into play is used to interpret the situation and to make recommendations. Consequently, as a result of this approach to the problem, we have a scientific attempt to maintain certain levels of nutrients within these tissues, whatever the nutrients may be. I am not thinking now in terms of one single nutrient; I am thinking in terms of all nutrients needed to make the cane plant healthy and productive. The scientific approach to keep the nutrient content within the particular tissues of the plant at a given level has been based on a large amount of accumulated data. It has been suggested that if we keep the tissues at these levels, we have a minimum amount of trouble in growing the plant. In order to maintain these levels of nutrients within the growing parts of the plant, it is absolutely essential that we have frequent samplings of the plant to make sure that we can catch the changes that take place. Consequently, with this approach we have frequent sampling periods to help achieve the objective.

Now, the other approach is a little bit different. In other words, at least as I see it, instead of trying to maintain a given balance of nutrients in the actively growing parts of the plant, this approach suggests that we find out what part of the plant can give us the most sensitivity, as far as composition is concerned, of the potential supply to the growing part of the plant of those nutrients which the plant needs. Consequently, if we are using the approach to sample the supplying power of the plant to the actively growing portion, then undoubtedly we will have an index that will not be so subject to the individual fluctuations which we pick up by frequent samplings of the growing part of the plant. Sampling of this index tissue might be used less often to achieve the same results. Moreover, in the second approach to the problem we have the idea of finding out what is the reservoir of some of the nutrients in the soil itself; that is, with respect to everything except nitrogen. You can't use the soil for nitrogen, although there has been some new information coming out from the mainland in which some scientists suggest that they can. Consequently, if we know what is the reservoir in the soil, than we

have an additional tool to help us project our thinking in the long-time production of the crop, both plant and ratoon. Then if we analyze the reservoir part of the plant, we can gain information that will project us across periods of stress, that might show up irregularly in a tissue that we might have to sample more frequently. As I visualize it, the differences in opinion are centered around a slightly different approach to the problem. And I am sure that as far as the folks involved are concerned, all are interested in finding the thing that is the simplest to do and that can be used with the most confidence in the production of sugar cane here in Hawaii. We are a small community. Consequently, it behooves us as scientists to pool our ideas. If one man has something and another man has something else, they should get together. We need to find out from the information at hand what can be done to improve the strategy with which we use crop logging in the production of sugar cane in Hawaii. That has been the objective of this seminar. That is the objective of the Experiment Station. We are trying to get information, and if the facts show we are 100 per cent all wet or 75 per cent all wet, that information is thrown out the window. If it becomes impractical, it is not going to be utilized. Consequently, we are interested in getting the information that will help improve: 1) the ease with which we can do the job, 2) the economy of our operations and still cover the same objective, and 3) the competence with which we use our particular tools.

There have been presented at this seminar data to indicate the possibility of greater sensitivity in using plant analyses from the stalk, for example. There has been evidence presented to suggest that these plant analyses might be less susceptible to ecological and climatological variations than those based upon the actively growing part of the plant. These are temporary suggestions made upon the accumulation of data at present. There are large amounts of data yet to be analyzed. If these data prove us wrong, our ideas will be changed without notice, as far as we are concerned. We also have data to indicate the possibility of economies in operations of a crop logging system as a result of more infrequent sampling periods.

This may be all well and good, but the question naturally comes up from the plantation men as to what should be done about it. If there is any one thing, I think we all need to keep open minds on everything that we heard here today. If we shut our minds in one direction or the other, we may be overlooking a good bet. Until any new changes come up on the basis of data obtained and analyzed and data yet to be obtained, and until these ideas can be developed so that they become practical working tools for plantations, I see no reason why the plantations should not continue exactly the way they have been with the present crop logging strategy. That has been the recommendation of the Station ever since Dr. Humbert and I came here. With the progress that we have been making, we feel that perhaps a little bit later, maybe even now, if anybody is interested—and I am not committing George Burr—it would be helpful if some plantations would help us check these new techniques with their existing strategy. For example, we would like to see whether or not we are as accurate under plantation operations as we have been with our coordinated experiments carried out under several varieties of climate and soil.

I think, all in all, we have had a mighty good conference. I've been very well pleased with it and I want to thank every individual who has participated in it

for all the time that has been spent in working up such excellent papers as a basis of discussions. Also, I want to thank every one of you who took part in the discussions, for the contributions that you have made. I'm sure that when we get this special edition of the Planters' Record with all of this material put together, we will want to sit down and digest some of it and look it over again. In the meantime, let's all of us keep plugging to see, irrespective of which one of these two approaches we are using, how we can improve our lot with respect to increasing the sensitivity, competence, and ease of operation of crop control.

As far as I am concerned, that is all I have to say by way of summary. If there is someone who wants to add anything, we have the time.

**W. W. G. Moir:** I'd like to clear a little bit on the subject of our experiments. I don't think it has been explained very clearly that this is not strictly for American Factors plantations. We came in with about 40 more assistants to help solve part of this problem of which is the most competent method to use. Our six different plantations with their agricultural research departments have worked with the Experiment Station. These data are going to be available to everybody when they are completed. They are not strictly American Factors plantations' data. We are in it just as much to help solve this problem as the rest of you. We thought we were getting nowhere without this cooperative approach and that is why we were in the picture.

**Al Stearns:** I would like to say, in commenting on the seminar, that I think this goes a good long step ahead of the HST meetings, and I think this sort of thing is well in order and we ought to have more of it.

**Keith Tester:** I would like to second Al's comments, and I would like to propose a vote of thanks to Dr. Baver and to his staff and to Dr. Clements and all of those outside who have taken part in this seminar. I feel that it is a tool that all of us on the plantations need in increasing our sugar production. Perhaps the most important thing now is not particularly the new tools but the refinement of the tools that we have. I think a seminar of this brand will give us the opportunity that we need to look over the tools that we now have. I think we owe these gentlemen a vote of thanks. I would like particularly to include Mr. Chinloy of Jamaica.

## EDITOR'S NOTE

The following is a brief resume of the philosophy and activities of the Experiment Station, HSPA, in the furtherance of crop-logging techniques in Hawaii.

1. The original interest of the Experiment Station began in 1938 when the Director suggested to Dr. H. F. Clements that the Station would be interested in studying and applying to sugar cane the principle of "the field log record" or "adjusted fertilization" then being introduced in the pineapple industry in an attempt to "use the plant as a quantitative index of its fertilizer requirements". As a consequence of this suggestion, experimental plots were set up at the Waipio and Kailua Substations, and an appropriation for a research assistant and laboratory supplies and equipment was made. This cooperation with the Department of Plant Physiology of the University of Hawaii remained in effect until 1948.

2. In 1941, the Department of Chemistry of the Experiment Station developed the leaf punch nitrogen technique. Rapid Chemical Methods were adapted to the Clements' method of crop control in 1944.

3. The Department of Physiology and Biochemistry of the Experiment Station was organized in 1947, and an intensive study of the fundamentals of the nitrogen nutrition of the cane plant was begun.

4. Although by 1948, the Clements' crop logging technique had been adopted by four plantations with good results over the then-existing practices, the Experiment Station did not assume any responsibility in helping to get other plantations interested in using this principle of crop control until the Department of Agronomy was reorganized in 1950. At this time, there was a considerable change in the philosophy of the Station's agronomic program. It was recognized that even though there may be deficiencies in the Clements' system of crop logging, it was sufficiently valuable for all plantations to use until worthwhile improvements could be made. Consequently, Grade A experiments were logged, as well as being sampled for soil analyses. Special equipment and extra help were added to the Department of Chemistry to run the analyses from experiments as well as to assist those plantations that did not have facilities to make their own analyses. Drying ovens were placed with the Island Representatives.

Plantations from American Factors and C. Brewer and Company, as well as Kahuku Plantation Company of Alexander and Baldwin, participated in the program and soon set up either their own, or cooperative, laboratories for making the analyses. The Theo. H. Davies plantations, McBryde Sugar Company of Alexander and Baldwin, and Gay and Robinson, have been participating on an experimental basis. The only change in techniques recommended by the Experiment Station has been the substitution of available soil phosphorus for leaf-sheath phosphorus because of serious deficiencies found in the latter. From 1950 through 1954, the Department of Chemistry made nearly 34,000 analyses involving samples from 24 of the 28 plantations.

5. In 1951, the Department of Agronomy, in cooperation with Ewa Plantation Company, Kohala Sugar Company, Hawaiian Commercial and Sugar Company, and Waialua Sugar Company, began a statistical analysis and study of six or more years of crop logging experience on these plantations. The objective of these analyses was to define the interrelationships of crop log factors under specific soil and environmental conditions in order to provide a better understanding of crop logging techniques. Many valuable relationships were observed in these studies. The results were published as Special Releases from the Experiment Station.

6. By 1952, the fundamental researches of the Department of Physiology and Biochemistry and of the Department of Agronomy, had indicated the need of a more reliable measure of nitrogen and phosphorus in the present crop logging methods. Experiments were suggesting that stalk analyses offered promise for improving the ease and accuracy of crop logging. With the cooperation of six American Factors plantations and Olokele Sugar Company of C. Brewer and Company, uniform replicated nitrogen-potash factorial experiments were installed to provide information correlating plant analyses and crop logging procedures with yields. The results from these experiments produced sufficient valuable information to warrant the discussions of the present knowledge of crop logging at this seminar.



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